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EURODELTA – II

Evaluation of a Sectoral Approach to Integrated Assessment Modelling including the Mediterranean Sea

by

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Executive Summary

The EURODELTA II (ED II) project is a continuing collaboration between the European Commission Joint Research Centre (JRC) at Ispra (Italy) and five air quality modelling teams at Ineris (France), the Free University of Berlin (Germany), Met.no (Norway), TNO (Netherlands) and SMHI (Sweden) in which the results from air quality model simulations are brought together in the JRC assessment toolkit and compared with each other and against data.

ED I examined the common performance of the models in predicting recent (2000) and future (2020) air quality in Europe using the concept of a model ensemble to measure robustness of predictions. The spread of predictions about the ensemble gave a measure of uncertainty for each predicted value. In a 2020 world the effect of making emission reductions for key pollutants of NO_x, SO_2, VOC and NH_3 independently in France, Germany and Italy, and of NO_x and SO_x in sea areas, was investigated. Source-receptor relationships used in integrated assessment (IA) modelling were derived for all the models and compared to assess how model choice might affect this key input. Some of this model comparison work has been reported[1234].

ED II builds on this project by taking a closer look at how the different models represent the effect on pollutant impacts on a European scale of applying emission reductions to individual emission sectors.

The reason for doing this is that the sound science basis behind air quality policy making on a European scale is based on an integrated assessment (IA) approach embodied in the IIASA[5] RAINS/GAINS models.

The IA methodology is fundamentally based on a model of economic activity (power generation, industrial manufacture, transport, agriculture etc.) that gives rise to present, and by means of a scenario approach, future emissions. Abatement technology can be applied to reduce emissions and each abatement possibility has a

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[1] Is regional air quality model diversity representative of uncertainty for ozone simulation ? (2006) *Geophys. Res. Lett.*, **33**, L24818, doi:10.1029/2006GL027610. Vautard, R., M. Van Loon, M. Schaap, R. Bergström, B. Bessagnet, J. Brandt, P.J.H. Builtjes, J. H. Christensen, C. Cuvelier, A. Graf, J.E. Jonson, M. Krol, J. Langner, P. Roberts, L. Rouil, R. Stern, L. Tarrasón, P. Thunis, E. Vignati, L. White, P. Wind.

[2] Evaluation of long-term ozone simulations from seven regional air quality models and their ensemble average.(2007) *Atmos. Environ.*, **41**, 2083-2097.Van Loon, M., R. Vautard, M. Schaap, R. Bergström, B. Bessagnet, J. Brandt, P.J.H. Builtjes, J. H. Christensen, C. Cuvelier, A. Graf, J.E. Jonson, M. Krol, J. Langner, P. Roberts, L. Rouil, R. Stern, L. Tarrasón, P. Thunis, E. Vignati, L. White, P. Wind.

[3] Evaluation of long-term aerosol simulations from seven air quality models and their ensemble in the EURODELTA study. (2008) *Atmos. Environ.*, submitted. Schaap, M., Vautard, R., Bergström, R., van Loon, M., Bessagnet, B., Brandt, J., Christensen, H., Cuvelier, C., Foltescu, V., Graff, A., Jonson J. E., Kerschbaumer, A., Krol, M., Langner, J., Roberts, P., Rouil, L., Stern, R., Tarrason, L., Thunis, P., Vignati, E., White, L., Wind, P., and P. H. J. Builtjes.

[4] Skill and uncertainty of a regional air quality model ensemble,(2008) *Atmos. Environ* submitted R Vautard, M. Schaap, M. van Loon, R Bergström, B. Bessagnet, J. Brandt, P.J.H. Builtjes, J. H. Christensen, C. Cuvelier, V. Foltescu, A. Graff, J.E. Jonson, A. Kerschbaumer, M. Krol, J. Langner, P. Roberts, L. Rouïl, R. Stern, L. Tarrasón, P. Thunis, E. Vignati, L. White, P. Wind.

[5] http://www.iiasa.ac.at/rains/index.html

cost, an effectiveness and a market penetration. To explore how future emissions may be reduced on a national scale in the most cost effective way so as to deliver improvements in environmental quality, an optimum mix of controls is sought. In the GAINS model this optimisation can also include structural changes such as a change in fuel use.

As a consequence of this process the final assessment of a viable future national emission ceiling target using integrated assessment implicitly assigns a distribution of sectoral burdens. These, when disaggregated, will identify, out of all the emission reductions it is possible to make, those which are least cost and thus “best” candidates for control. Such considerations can lead to the making of enabling legislation such as the large combustion plant directive (LCPD)

An essential part of the IA process is estimating the effect of the emission reduction on pollutant impacts. The pollutant impacts considered in current policy, for example in the Clean Air for Europe (CAFE) program, are manifold. They divide into:

- damages to ecosystems, crops and forestry by acid deposition, eutrophication and ozone;
- damages to human health (including both mortality and morbidity) through exposure to ozone and fine particle concentrations.

The IA process uses a source-receptor relationship (SRR) approach to relate emissions to their environmental and health impacts. The SRRs provide a country to grid mapping whereby the change in a national emission results in a calculated change in concentration and deposition at every grid square (50 x 50 km) in the model domain. The impact end-points for each square can then be calculated using indicators of risk to ecosystems and health developed by the environmental effects and health communities.

The relationships (SRR) presently used in Integrated Assessment are developed from a set of scenario calculations made with the EMEP air quality model[6]. The model uses an emission inventory that is geographically accurate at model scale and so the distribution of base-case emissions is well represented as are the base impacts. The SRR are developed by changing the national emissions from the base case and calculating the response in air concentrations and depositions. The change is distributed over all the emission sources in proportion to their contribution and so the geographic distribution of sources is assumed invariant.

As described above, it is highly unlikely that the cost optimisation approach used in the IA process would distribute emission reductions in such an even manner across sectors. It is much more likely that the sectoral burdens will be different. This would mean that, in a future lower emission world, the geographic pattern of emissions would change. Furthermore, because proximity of sources to the receptors is important , the positioning of sources relative to the most sensitive receptors may be important in the optimisation process. For example sectors with emissions that closely follow the population distribution may contribute more to impacts involving human health than sectors which do not.

ED II therefore set out to take a first look at whether there are differences in the size of effect of emission reductions if they are applied to single sectors compared with all sectors. As such it aims to assess the usefulness of introducing sectoral source

[6] http://www.emep.int/UniDoc/index.html

receptor relationships and inform on the effectiveness of reducing emissions in those sectors presently differentiated by the optimiser in IA models.

The geographic scope for the ED II modelling is the same as that for ED I. Each participating model used its native grid. The common overlap area of grid has a geographic scope which runs from approximately 10 degrees west to 24 degrees east and between 36 and 57 degrees North. The overlap area does encompass most countries of the European Union, the principle omissions are the Baltic countries, Finland, Sweden, Denmark and Cyprus. The United Kingdom (except Northern Scotland), France, Germany and Spain, in which the sectoral emission reductions are tested, are well within the domain. These four countries account for 53% of the total EU population. The Mediterranean Sea extent east of the Aegean and south of Turkey is not included in the overlap area. Four of the models have larger domains and cover almost all of Europe.

Emission reduction scenarios for the Mediterranean Sea were also included because emissions from sea areas do affect concentrations of pollutants on land and properly need to be taken account of when determining air pollution policies. The role of sea areas has previously been explored in studies supporting the EU National Emission Ceilings Directive (NECD) review. The International Maritime Organisation is considering the need for further regulation of emissions from shipping as part its review of Annexe VI of the MARPOL convention. The European Commission is committed to reviewing its policy on ship emissions in 2008.

A total of 60 different emission scenario calculations were run using meteorology from 1999. Sectors were defined using the SNAP97 designation and main focus was on Sectors 1,2,3,4,7 and 10 with some scenarios including sectors 6 and 8. Sector definitions are given in the introduction. Although the time-line for the scenarios is 2020 in line with the EU CAFE study and with the NECD review, an extra set of three 2010 scenarios was run for the Mediterranean Sea. These examine the effect of EU legislation requiring the use of a 0.1% S fuel for ships at berth in ports and the use of a maximum 1.5% S fuel for ferries.

Results from all of the models were collated and presented in a computer tool, the ED toolkit, developed and operated by the European Commission Joint Research Centre at Ispra (JRC). The toolkit allows detailed comparison (visual and numerical) of model results on a common grid basis. The toolkit and model data will be made available to allow others to make more detailed studies of the results than can be described here. The toolkit is described in Appendix C.

It is not practical to present the full country-to-grid mapped source receptor relationship in a written report. Therefore we have focussed on aggregate measures representing the net country-to-self and the net country-to-domain mappings. The latter represents the main European policy target of ensuring that national emission ceilings are chosen to the overall benefit of the European Community. The former represents, for these countries[7], the largest impact and, for the country itself, the most useful information on the efficacy of the sectoral controls it might choose to enforce. Because the policy metric is a function of the concentration/deposition in each cell and might be an environmental or a human health impact we have represented results on both a population weighted and on a non-weighted basis to see if the receptor distribution affects the results. We have, for reasons of practicality, not been able to go further and include an urban uplift to concentrations to account for city conditions (which would likely enhance sector 2 and sector 7

[7] For smaller countries the ratio of transboundary to domestic impacts may be greater

contributions) or to incorporate the detailed land-use and critical load databases to provide quantified acidification and eutrophication results.

The results are expressed as a response to a change in emission and so an effectiveness (pollutant reduction per kilo-tonne of pollutant abated) measure is derived. The expression “emission potency” is also used to describe differences in effectiveness. Thus if one of two reduction measures is said to have a greater potency the effectiveness is higher.

A key finding of the study is the high level of agreement between models across all the scenarios studied regarding the effectiveness of sectoral reductions. This consistency in results is encouraging as it means that the conclusions of this report are robust.

In the findings below the “ALL” scenario refers to the case where emissions are reduced proportionately across all sectors as is assumed in modelling for policy.

Regarding particulate matter concentrations:

- All the models agree that there are differences in effectiveness of emission reductions between sectors. This is broadly consistent with a physical interpretation that the more effective reductions are for sectors where proximity of the source of emission to people is greatest. Thus, higher effectiveness is seen from sectors emitting at low level and distributed according to population and lower effectiveness is seen for sectors emitting from large point sources. Point sources are fewer in number, emissions are released from great height (taking plume rise into account) and generally the association with populated areas is less. Quantitatively, effectiveness depends on the distance from the source as concentrations decrease with distance. Assimilation of results into SRR’s that reflect the influence of changes in A on B also reduces effectiveness as the geographic area of B increases and includes more distant lands.
- The differences between sectors is greater for population weighted compared with non-weighted concentrations.
- The above is true whether the impact is assessed EU wide or in the country in which the emission control takes place.
- All models show that the ‘ALL’ scenario gives a significantly different effectiveness to the sectoral effectiveness and this applies to all the pollutants contributing to $PM_{2.5}$ concentrations (NO_x, SO_x, $PPM_{2.5}$).
- The sectoral response is not the same in all countries and is different for each pollutant and in particular the potency of ammonia emissions as they affect $PM_{2.5}$ is much larger (by a factor of two) in the UK than for other countries.

These results can be quantified by looking at the ratio of sector effectiveness to the ‘ALL’ scenario effectiveness for $PM_{2.5}$ concentrations. We extract results from one model, Model 3 in the toolkit which is the EMEP model used for policy studies. Only the population weighted results are tabulated as, for PM, these are the most relevant for the evaluation of health effects. Firstly for the Europe wide impact (which includes the country of origin) we find.

Relative efficiency of sectoral SO_2 reductions for $PM_{2.5}$ impacts on Europe.

	Sector efficiency /All sectors efficiency		
	1	3	8
FR	0.74	1.06	-
DE	0.86	1.03	-
ES	1.01	1.03	1.06
UK	0.86	0.96	-

Relative efficiency of sectoral NO_x reductions for $PM_{2.5}$ impacts in Europe

	sector efficiency/ALL sectors efficiency		
	1	3	7
FR	0.91	0.87	1.05
DE	0.80	0.84	1.06
ES	0.65	0.93	1.15
UK	0.74	0.79	1.21

Relative efficiency of sectoral Primary PM reductions for $PM_{2.5}$ impacts in Europe

	sector efficiency/ALL sectors efficiency				
	1	2	3	4	7
FR	0.64	1.03	0.63	1.08	1.26
DE	0.51	1.07	0.55	1.38	1.05
ES	0.39	1.78	0.52	0.84	1.09
UK	0.47	1.04	0.58	1.31	1.51

Secondly, for impacts in the country of reductions we find:

Relative efficiency of sectoral SO_2 reductions in France on $PM_{2.5}$ impacts in France, in Germany on Germany, in Spain on Spain and in the United Kingdom on the UK.

	Sector efficiency /ALL sectors efficiency		
	1	3	8
FR	0.49	0.86	-
DE	0.76	0.88	-
ES	0.76	0.94	1.30
UK	0.75	0.82	-

Relative efficiency of sectoral NO_x reductions in France on $PM_{2.5}$ impacts in France, in Germany on Germany, in Spain on Spain and in the United Kingdom on the UK.

	sector efficiency/ALL sectors efficiency		
	1	3	7
FR	0.70	0.59	1.16
DE	0.69	0.77	1.14
ES	0.48	0.80	1.33
UK	0.55	0.66	1.44

Relative efficiency of sectoral primary PM reductions in France on $PM_{2.5}$ impacts in France, in Germany on Germany, in Spain on Spain and in the United Kingdom on the UK.

	sector efficiency/ALL sectors efficiency				
	1	2	3	4	7
FR	0.40	1.02	0.40	1.08	1.47
DE	0.38	1.09	0.44	1.45	1.07
ES	0.26	1.96	0.41	0.80	1.12
UK	0.33	1.03	0.45	1.38	1.62

Regarding ozone (as measured by SOMO35)

- There are considerable country differences in the response of SOMO35 to NOx reductions from different sectors. This is a consequence of the prevailing chemical regimes and spatial distribution of emissions, in particular, large point source emissions in the different countries. In France sector 1 controls have less effect than other sectors which are similar to the 'ALL' scenario. In Germany and Spain there is much less variation between sectors. In the UK SOMO35 is predicted to increase rather than decrease with NO_x reductions albeit by a very small amount indicating that the UK is still in a NOx limited ozone regime in 2020.

There are some doubts about the robustness of the studied SOMO35 response to VOC controls. To limit the number of calculations needed we assumed that changes in SO_2 emissions would have no effect on ozone when partnered with VOC emission changes. This is not necessarily the case. Unfortunately we did not carry out any cases where SO_2 and VOC were varied independently and which could have been used to quantify any effect. Therefore the following observation from the study may not be robust. It is included for completeness and, because interested parties using the toolkit would find the same result, to ensure this caveat is recorded.

- There are considerable differences in the response of SOMO35 to VOC reductions across countries. In France and Germany differences in effectiveness from different sectors is small. In Spain and the United Kingdom emission reductions in the transport sectors are much more effective than the all scenario and the results are dependent on whether population or area weighted values are used, differences being greater for the population weighted results.

Regarding deposition we find::

- Differences in sectoral efficiency were smaller for deposition than for air concentrations when averaged over the whole domain. Differences in sectoral approaches are larger in the country of emission.
- Differences in sectoral efficiency were more varied for oxidised Nitrogen deposition than for oxidised Sulphur deposition. Deposition of nitrogen in the country of emission change was generally less than that of Sulphur indicating greater transboundary transport of Nitrates.
- For Sulphur, all models predicted that emission reductions in sector 1 were less effective than the ALL scenario for sulphur. Only a single case for Spain which looked at emissions from sectors 7 and 8 combined had a greater efficiency. The amount of Sulphur retained on land in the whole domain was

generally less than twice that retained in the country of emission. Sectoral differences were less marked when looking at the whole domain than when looking at individual country results.

- For Nitrogen, all models predicted a lower efficiency for emission reductions in Sector 1 compared with the 'ALL' scenario for deposition within the country of control. Emissions reductions in sector 7 were generally more effective than the 'ALL' scenario. Again, if retention in the entire domain was considered then sectoral differences became smaller. The amount of Nitrogen retained on land in the whole domain was about twice that retained in the country of emission. Only about half of all Nitrogen emission reduction is accounted for by deposition to land within the domain.
- Reduced nitrogen deposition is dominated by the agriculture sector and so relative efficiencies do not apply. Dispersion is of much shorter range than for oxidised nitrogen with much more retained in the domain.
- A useful extension of this work would be to include information on detailed ecosystem impacts (critical loads, forest, crop and ecosystem locations) as weighting factors for the deposition calculations.

Regarding Mediterranean Sea Emissions:

- Emission changes benefit a limited number of countries: Greece, Italy, Malta, Slovenia and Spain.
- The current legislation (use of 1.5% S in Ferries) reduces 2010 concentrations in these countries by a maximum of 0.5%.
- The current legislation (use of 0.1% S in ports) reduces 2010 concentrations in the mainland countries by a maximum of 0.8% in Italy. Malta benefits more proportionally, ~ 5%, by virtue of its location and size.
- In a 2020 world, emission changes brought about if the Mediterranean were declared a SECA would produce a benefit of up to ~ 3.75% in $PM_{2.5}$ concentrations for Greece, Italy, Slovenia and Spain. Malta would benefit more proportionally because land based emissions contribute less to PM concentrations (which are lower than in other countries)
- In a 2020 world half of the benefit for $PM_{2.5}$ concentrations can be gained by declaring the 12 mile zone a SECA.
- Almost identical results are obtained if the emissions growth up to the year 2020 were only 2% per annum compared with the base case assumption of 2.5%. That is a low growth scenario gives the same difference in $Pm_{2.5}$ concentrations from the base case as declaring the 12 mile zone a SECA.
- The effectiveness of emission reductions in the Mediterranean is different according to whether emission reductions take place in the 12 mile zone or across the whole sea. Emission reductions within the 12 mile zone are about twice as effective (reduction in PM per kt of emission) than applying controls over the whole Mediterranean area.
- The $PM_{2.5}$ effectiveness of ship controls over the whole Mediterranean is largest (of the main-land countries) for Italy and amounts to ~0.2 ng/m^3/kt for reductions of SO_2 or of NO_x.
- The potency of NO_x reductions on SOMO35 for the most affected countries is of order 0.25 ppb.days/kt NO_x.

Regarding the relative potency of land and sea emissions as they affect $PM_{2.5}$

- With respect to $PM_{2.5}$ concentrations across the modelled domain the effectiveness of reducing SO_2 or NO_x emissions from ships is a factor 6 (SO_2) and 10 (NO_x) smaller than the effectiveness of on-land emission reductions made in Germany, and a factor 4(SO_2) - 6 (NO_x) less than the emission changes in France or the UK.

This study has shown that there are important differences between sectors in the amount of concentration(deposition) reduction obtained by changing a pollutant emission. This difference is not accounted for in the present process used to evaluate future national emissions ceiling reductions for both beneficial effect and cost-effectiveness. This raises the possibility that, when national bodies consider how to implement an emission ceiling taking account of the information used in deriving that ceiling, choices might be made that are less effective than expected.

It is recommended that, at minimum, validation calculations are carried out as part of the NEC process to examine if the implied sectoral reductions are able to deliver the intended benefits. If sectoral weights could be incorporated into the integrated assessment itself then this may lead to an overall better recommendation for emission ceilings.

Contents

1. Introduction

European Air Quality policy needs have been very well met by an Integrated Assessment (IA) approach which informs on the most cost-effective means to reduce national emissions in order to mitigate transboundary pollutant impacts and achieve environmental improvement targets. Emission reductions also benefit the country in which they take place and so the focus of policy is now to improve the total European condition rather than target specific transboundary influences.

The inputs to the IA model that are used to calculate emissions and the cost and potential for abatement, operate at a sectoral level. However, the effects module, through which the benefits of emission reductions are calculated, does not. It uses a set of source-receptor relationships that represent a country-to-grid-cell mapping such that the effect of change in a national emission produces a change in pollutant concentrations (or deposition) in all grid cells. These changes may then be multiplied by a weighting factor, for example population in each cell, and summed to produce an environmental damage measure. Examples are human exposure to PM or the number of ecosystems above critical load.

Because the IA method produces detailed sectoral information, especially information about where the largest emission reductions can be made at least cost, it is highly likely that any controls put in place to meet an emission ceiling will require different emission reductions from different sectors. It is therefore important to establish whether such reductions would actually have the intended effect. This is especially important as the system that was originally developed for eco-system protection is being expanded to account for the mitigation of health and climate effects as well.

This project was carried out to provide the first information on whether a sectoral approach to emissions reduction and a national approach to emissions reduction would provide the same benefits in terms of the amount of benefit achieved per unit emission reduction which we will call effectiveness or potency.

It is important to note that, even if differences are found, there are several factors to be considered before the overall effect on policy decisions is known. For example the emission from an individual sector might not be large even if a reduction were very effective so the total benefit might be small. Similarly an effective but very costly reduction might not be achievable. A cause for concern would be the finding that an emission that is large and cost-effective to control would be found to have a lower effectiveness than assessed using a non-sectoral approach. This could lead either to policy targets not being met or the final costs of control to meet targets being underestimated.

EURODELTA II (ED II) is a continuing collaboration between the European Commission Joint Research Centre (JRC) at Ispra (Italy) and five air quality modelling teams at Ineris (France), the Free University of Berlin (Germany), met.no (Norway), TNO (Netherlands) and SMHI (Sweden) in which the results from air quality model simulations are brought together in an assessment toolkit that allows model predictions to be compared with each other and against data.

The geographic scope for the ED II modelling is the same as that for ED I. Each participating model used its native grid and the common overlap area of grid defines the geographic scope which runs from approximately 10 degrees west to 24 degrees east and between 36 and 57 degrees North. Four of the models have larger domains. The overlap area does encompass most countries of the European Union, the principle omissions are the Baltic countries, Finland, Sweden, Denmark, Romania, Bulgaria and Cyprus. The United Kingdom (except northernmost Scotland), France, Germany and Spain, in which the sectoral emission reductions are tested, are well within the domain. The Mediterranean Sea extent east of the Aegean and south of Turkey is not included in the overlap area.

In all a total of 60 different scenario calculations were run to examine the effect of sectoral controls on land and changes to Mediterranean Sea emissions. Although the time-line for most of the scenarios is 2020 to be consistent with the EU CAFE study and the NECD review, a set of three 2010 scenarios was run for the Mediterranean to examine the effect of the recent (2005) EU legislation on emissions from ships. This legislation requires use of a 0.1% S fuel in ports and the use of a maximum 1.5% S fuel for ferries in service in European waters.

The model common input data was co-ordinated, quality checked and distributed by JRC via the EuroDelta website (http://aqm.jrc.it/eurodelta/). JRC collected and processed all of the modelling results. A computer tool, the ED toolkit, was developed by JRC to allow selected results to be compared visually and extracted from the database for numerical evaluation. To compare model results they have to be on a common grid basis and the ED toolkit will recast results to either an EMEP or a latitude-longitude projection. Numerical output is available for the EMEP projection and all of the results presented here use that projection.

The participants ran their own models to as common a set of emission scenarios as possible. Anthropogenic inputs were fixed and provided by the JRC but there are inevitable small changes in biogenic inputs and in boundary conditions.

The different model implementations naturally result in numerically different results. It is not the intention of this report to discuss in any detail the differences between models. That discussion was captured in the ED I project which examined the common performance of the models in predicting recent (2000) and future (2020) air quality in Europe. The concept of a model ensemble to measure the robustness of the predictions was used. The spread of predictions about the ensemble gave a measure of uncertainty for each predicted value. In a 2020 world the effect of making emission reductions for key pollutants of NO_x, SO_2, VOC and NH_3 independently in France, Germany and Italy, and of NO_x and SO_x in sea areas, was investigated. Source-receptor relationships used in integrated assessment (IA) modelling were derived for all the models and compared to assess how model choice might affect this key input.

The objective of the study is to evaluate whether sectoral emission reductions would result in different source receptor relationships to those used in policy. It is very difficult to compare source receptor relationships directly because they are defined as a country to grid mapping and thus comprise very large matrices. It is necessary to aggregate the results. For example EMEP regularly publishes “blame” matrices” in its annual status reports that reflect the change in concentration of a pollutant in one country for a 15% reduction of precursor emission in another country.

In this work a normalised measure is used which is the sum of the response of all of the grid cells in a country (or in the domain) divided by the magnitude of the emission change. This is a measure of effectiveness or “potency”. If it is zero then making an emission change has no effect, if it is positive then making an emission reduction produces a benefit. If two reduction measures have different effectiveness measures then the measure giving the largest effectiveness is the more potent. Depending on the relevant policy endpoint the grid cell response can be weighted. Here we use population weighting to describe the $PM_{2.5}$ response because the concern with $PM_{2.5}$ is the effect on human health. It is thus sensible to give more weight to grid cells in populated areas. For deposition effects we do not have information on ecosystem numbers and critical load data and so grid cell area is used. Note that the grid cell areas are very similar so that the weighting factor is small.

For reasons of space and policy relevance the only pollutants discussed in this report are fine particulate matter ($PM_{2.5}$), SOMO35 (which is a count of cumulative daily ozone hours exceeding 35 ppb and is the currently accepted human health metric for ozone impacts), sulphur and reduced nitrogen deposition (which represents acidic deposition) and deposition of oxidised nitrogen and ammonia which are both eutrophying and acidifying pollutants.

The land based sectors that were investigated were, following the SNAP97 designation:

Sector 1. COMBUSTION IN ENERGY AND TRANSFORMATION INDUSTRIES (stationary sources). These are large combustion plant sources with emissions from tall stacks. The sources are not uniformly distributed around the country-side but are concentrated into industrial areas

Sector 2. NON-INDUSTRIAL COMBUSTION PLANTS (stationary sources). This sector includes domestic combustion. Sources are low level and distributed more in-line with population density.

Sector 3 COMBUSTION IN MANUFACTURING INDUSTRY (stationary sources)
Contains a mixture of high and low level sources in mostly industrial areas

Sector 4: PRODUCTION PROCESSES (stationary sources)
Contains mostly low level sources in industrial area.

Sector 6: SOLVENT AND OTHER PRODUCT USE
Widely distributed low level sources of volatile organic compounds from both industrial and domestic activity.

Sector 7: ROAD TRANSPORT
Low level sources, distributed widely in both populated and non-populated areas in the case of main highways.

Sector 8: OTHER MOBILE SOURCES AND MACHINERY
Low level sources including national shipping emissions where ship's entire journey lies within national borders. In this project the international shipping emissions were also included in sector 8.

Sector 10: AGRICULTURE
Widely distributed low level source of mainly ammonia.

The detailed scenarios are described in section 2. The base case emission inventory for 2020 for the land based sources was the current legislation scenario consistent with that used for the CAFE program.

The Mediterranean Sea scenarios included a 2010 to evaluate the potential benefit of the recent (2005) EU legislation governing ferries and ships in port, namely that ferries in EU waters should use a fuel containing a maximum 1.5%S and that all ships in port should use a fuel containing a maximum 0.1%S.

The main scenarios for 2020 were carried out to look at the impacts of projected ship emissions against the projected lower land emissions of that year.

The emission inventory for the Mediterranean was projected from a 2005 inventory developed by ENTEC for Concawe and drawing on their previous experience in generating a Europe-wide inventory (base year 2000) for the European Commission.

2. Description of scenarios

To be realistic the emission reduction scenarios used in this simulation must consider what emissions are available in each sector in each country so it is not realistic to impose a constant emission reduction across all countries.

For each country and for the main pollutants $NO_{x,}$ SO_2, NH_3, VOC, and primary $PM_{2.5}$ we have set an absolute reduction amount. The base case for each country has this reduction distributed across the emissions from each sector in proportion to their contribution. This is referred to as the "all" scenario and best represents the country reduction used in CAFE studies.

Next we look at how that same amount of reduction could be achieved by making an explicit reduction in each of the major emitting sectors for that pollutant. These are sector specific reductions. Because the amount of reduction for each sector is different the results have to be normalised for comparison purposes. Thus we will use the change in target pollutant per unit change in emission. Here the unit of emission is in kilotonnes. Some additional runs are included to test linearity. The linearity test results are included in this presentation but detailed analysis is discussed in the team reports to Concawe.

Finally a case was run with the reductions in the named sector together. This is called the "combined" scenario and can be compared with the "all" scenario.

The scenario reductions are listed below in Table 1. As the number of permutations is large there was some pair-wise matching on the assumption that some emission reductions have an independent effect on pollutant concentrations. Thus SO_2 reductions (affecting secondary $PM_{2.5}$) were paired with VOC reductions (affecting Ozone) and NO_x reductions (affecting secondary $PM_{2.5}$) were paired with primary $PM_{2.5}$ reductions.

None of the models in this project calculated secondary organic aerosol because the uncertainties in the formation rates are too large. Hence there is no direct link between VOC emissions and particulate matter.

The assumption that the SO_2 emission effects on ozone was negligible compared with that of VOC emissions may not be sound. This is discussed in the MATCH team report to Concawe. Unfortunately no control runs were made whereby SO_2 and VOC were varied independently. We will report the results but on the strong caveat that they may not be robust.

				Emissions Reductions in ktonnes/year with Percent of Total 2020 Emissions Remaining Shown in Parenthesis				
Scenario	**Country/Area**	**Sectors**	**Pollutant(s)**	**NOx**	**PM2.5**	**SOx**	**VOC**	**NH3**
0	**BASE CASE 2020 CLE**							
1	**France**	All	NOx+PM2.5	230 (71.9%)	62 (62.8%)			
2		All	SOx+VOC			110 (68.1%)	150 (83.8%)	
3		SNAP 1	NOx+PM2.5	40 (95.1%)	3 (98.2)			
4		SNAP 1/4	SOx+VOC			40 (88.4%)	30 (96.8%)	
5		SNAP 2	PM2.5		45 (73.0%)			
6		SNAP 3	NOx+PM2.5	100 (87.8%)	2 (98.8%)			
7		SNAP 3/6	SOx+VOC			70 (79.7%)	120 (87.0%)	
8		SNAP 4	PM2.5		10 (94.0%)			
9		SNAP 7	NOx+PM2.5	90 (89.0%)	2 (98.8%)			
10		SNAP 10	NH3					250 (63.8%)
11		Combined	NOx+PM2.5	40/100/90 (71.9%)	3/45/2/10/2 (62.8%)			
12	**Spain**	All	NOx+PM2.5	200 (70.6%)	25 (72.4%)			
13		All	SOx+VOC			97 (71.1%)	180 (74.3%)	
14		SNAP 1	NOx+PM2.5	50 (92.7%)	3 (96.7%)			
15		SNAP 1/4	SOx+VOC			40 (88.1%)	70 (90.0%)	
16		SNAP 2	PM2.5		12 (86.8%)			
17		SNAP 3	NOx+PM2.5	90 (86.8%)	1 (98.9%)			
18		SNAP 3/6	SOx+VOC			40 (88.1%)	100 (85.8%)	
19		SNAP 4	PM2.5		8 (91.2%)			
20		SNAP 7	NOx+PM2.5	60 (91.2%)	1 (98.9%)			
21		SNAP 8/7	SOx+VOC			17 (94.9%)	10 (98.6%)	
22		SNAP 10	NH3					125 (66.2%)
23		Combined	NOx+PM2.5	50/90/60 (70.6%)	3/12/1/8/1 (72.4%)			
24	**Germany**	All	NOx+PM2.5	150 (81.4%)	25 (77.5%)			
25		All	SOx+VOC			60 (81.9%)	120 (84.6%)	
26		SNAP 1	NOx+PM2.5	50 (93.8%)	4 (96.4%)			
27		SNAP 1/4	SOx+VOC			50 (85.0%)	20 (97.4%)	
28		SNAP 2	PM2.5		8 (92.8%)			
29		SNAP 3	NOx+PM2.5	50 (93.8%)	4 (96.4%)			
30		SNAP 3/6	SOx+VOC			10 (97.0%)	100 (87.1%)	
31		SNAP 4	PM2.5		8 (92.8%)			
32		SNAP 7	NOx+PM2.5	50 (93.8%)	1 (99.1%)			
33		SNAP 10	NH3					125 (79.3%)
34		Combined	NOx+PM2.5	50/50/50 (81.4%)	4/8/4/8/1 (77.5%)			
35		Combined	SOx+VOC			50/10 (81.9%)	20/100 (84.6%)	
36		All	NOx+PM2.5	100 (87.6%)	12.5 (88.7%)			
37		All	SOx+VOC			30 (91.0%)	60 (92.3%)	
38		SNAP 1/4	SOx+VOC			25 (92.5%)	10 (98.7%)	
39		SNAP 10	NH3					62.5 (89.6%)
40	**UK**	All	NOx+PM2.5	250 (69.4%)	13 (80.7%)			
41		All	SOx+VOC			65 (68.9%)	90 (89.8%)	
42		SNAP 1	NOx+PM2.5	100 (87.8%)	2 (97.0)			
43		SNAP 1/4	SOx+VOC			30 (85.6%)	10 (98.9%)	

				Emissions Reductions in ktonnes/year with Percent of Total 2020 Emissions Remaining Shown in Parenthesis				
Scenario	**Country/Area**	**Sectors**	**Pollutant(s)**	**NOx**	**PM2.5**	**SOx**	**VOC**	**NH3**
44		SNAP 2	PM2.5		4 (94.1%)			
45		SNAP 3	NOx+PM2.5	90 (89.0%)	2 (97.0%)			
46		SNAP 3/6	SOx+VOC			35 (83.2%)	80 (90.9%)	
47		SNAP 4	PM2.5		4 (94.1%)			
48		SNAP 7	NOx+PM2.5	60 (92.7%)	1 (98.5%)			
49		SNAP 10	NH3					90 (71.0%)
50		Combined	NOx+PM2.5	100/90/60 (69.4%)	2/4/2/4/1 (80.7%)			
51	**MED SEA**	Base Case 2010 With 2.7% RFO and 0.1% Gasoil						
52		Base Case 2010 But 1.5% On Ferries						
53		Base Case 2010 But 0.1% S on all ships at berth in all EU ports						
54		Base Case 2020						
55		Base Case 2020 With Only 2% Growth						
56		Base Case 2020 + Mediterranean as 1.5% S SECA						
57		Base Case 2020 + 12m limit as 1.5% SECA in EU Inc Gibraltar straits						
58		Base Case 2020 + 12m limit as 1.5% SECA in EU Excl Gibraltar straits						
59		Base Case 2020 +Aegean Sea alone as a 1.5% SECA						
60		Base Case 2020 with 40% NOx Reduction						

Table 1. Scenario Table of Emissions for the ED II project

3. Methodology used

The data management of the project was conducted by the European Commission Joint Research Centre (JRC) at Ispra. The platform used was the toolkit first developed for the City Delta projects and extended for the Euro Delta I project. The toolkit itself is described in Annexe III.

3.1 Input Data.

The JRC standardised and quality assured the emission inventory data on an EMEP grid projection. This data was then taken by each modelling group and transferred to their modelling projection. A series of quality assurance checks were carried out to verify that the emissions had been correctly transformed. These checks are described in Annexe II which also provides a table of how the emissions were split by height.

The on-land 2020 emission data is consistent with the Current Legislation scenario used in the CAFE program. Information on sectoral contributions was used to allocate emissions in each EMEP grid cell to the relevant sectors. A set of source heights were agreed for the different sectors with the definitive source height distribution being set by the EMEP model which included a consideration of plume rise. The other groups allocated emissions to the nearest compatible vertical layer in their models.

3.2 Processing of Results

Modellers returned the model results on their own grid projections to JRC in an agreed file format. This data was processed into a compatible form for use in the tool-kit wherever the output variable is a derived quantity. Verification of results was carried out by inspection in the toolkit by both the modellers themselves and in meetings of the study group. In view of the huge number of calculations carried out and the number of data-files involved, relatively few errors were found. A very small number of model/scenario/pollutant combinations have been rejected as unrealistic with file mislabelling the likely cause.

The EuroDelta toolkit provides both a graphical display of the data for visual inspection and, optionally, as data files, described below. Thirty-six different output parameters can be selected. These include concentrations of key intermediate species, the prime pollutants and derived quantities. Particulate matter can be output as total PM2.5 and as primary PPM2.5. Inorganic secondary PM can be output as sulphate, nitrate and ammonium or as total secondary inorganic. Black carbon and organic carbon can be separated. Wet and dry deposition can be separated out from total deposition of sulphate, nitrate and ammonium. Ozone impacts can be expressed in 5 different ways according to required threshold and time-weighting. The PM impacts can be converted into population Years of Life Lost (YOLL) according to the methodology used by IIASA in the CAFE work.

For any of the output parameters the toolkit can difference the results from any two scenarios. The convention used in this report is that the first scenario is the base case CLE; the second scenario is an emission reduction scenario. As the reduction scenario (should) lead to lower concentrations the difference is positive. Thus a positive value is a decrease in the respective quantity and a negative value is an increase.

The visual results can be inspected on a longitude-latitude grid, whereupon the EMEP and MATCH model results are remapped, or on the EMEP grid whereupon the results of all the models (except EMEP) are remapped. The results can be weighted by population, and for the on-land scenarios scaled by emission reduction although for results prepared here all scaling was done by post-processing results output as a text file (as described below).

In the EMEP grid projection the numerical value of the selected output parameter in each grid cell (approx 50*50 km) can be printed to a text file for further analysis. As per the information on the MSC-W web-site, each EMEP grid cell has an associated country “fraction” (EMEP cells can sit astride country borders) by area. The country averaged concentration of a pollutant is obtained by summing the cell contents each multiplied by the country fractions and cell area, then dividing by the country area. The population weighted country average concentration is obtained by including the population in each grid cell into this procedure. The country integrated deposition is obtained by summing the deposition per unit area multiplied by the cell area belonging to the country. It is recognised that this is an incomplete description of the environmental impact because information on critical loads and ecosystem, crop and forest locations is needed to assess the full impacts. Such an assessment can be made by post processing the ED II output files. It is beyond the scope of the present work.

For convenience each data output file is headed by the country data comprising the average or integrated or population weighted results as required. The results presented in this report are all based on the information in this header file which gives values for 24 of the 25 countries known previously as the EU-25. Some of these territories are only partially included, depending on the individual model domain. Null results are output for Cyprus which lies to the east of the modelled domain. In some of the results that follow Cyprus appears on the country list. This is an error and should be ignored.

4. Results

In the following sections the effect of sectoral emission changes on $PM_{2.5}$ concentrations, on SOMO35 and on deposition are compared. To compare the effectiveness of emission changes the results have been normalised. Results are expressed as:

$$\frac{\Delta\ \text{concentration}}{\Delta\,\text{emission}} \text{ or } \frac{\Delta\,\text{deposition}}{\Delta\,\text{emission}} \text{ as appropriate.}$$

For air concentrations of pollutants the normalisation uses the actual precursor emission with the exception of NO_x which is treated as a NO_2 equivalent in the usual way.

For deposition the toolkit outputs results in mass units of sulphur or nitrogen whereas the emissions are for SO_2, NO_2 (equivalent) and NH_3. Accordingly the emissions have been converted to S, N (oxidised), N (reduced) for normalisation purposes.

NOTE: Because the changes are all small the pollutant concentrations have been multiplied by a factor 1000. Thus the PM concentrations are in ng/m^3 instead of the more usual μg/m^3 (charted unit ng/m^3/kt) and SOMO35 is in ppb.days and not ppm.days (charted unit ppb.days/kt)

$PM_{2.5}$ comprises primary and secondary particles and is affected by emission changes to primary particles (PPM), as well as the precursors to secondary PM which are SO_2, NO_x and NH_3. To minimise the number of model simulation runs we made some assumptions:

- That NO_x and PPM emission reductions can be paired on the basis that PPM does not affect the ozone dependence on NO_x and that PPM reductions do not affect the secondary particulate matter dependence on NO_x and vice-versa.
- That SO_2 and VOC emission reductions can be paired and SO_2 reduction changes do not affect the ozone dependence on VOC and that the VOC changes do not affect the secondary particulate matter dependence on SO_2 (secondary organic aerosols being neglected).

When the results were analysed we found that the assumption that small changes in SO_2 and VOC emissions are independent with regards to ozone is not perfect. This needs to be investigated further using simulations in which SO_2 and VOC emissions are made separately. We will report the ozone response to VOC changes found in this study but, pending full investigation of the interdependence they must be regarded as preliminary.

$PM_{2.5}$ concentrations are affected by both NO_x and primary PM emissions. In the combined NO_x and PPM scenarios the effects are taken as additive. The PPM effect was calculated first and then the NO_x effect was calculated using:

$$\frac{\Delta\ PM_{2.5} - \Delta\ PPM_{2.5}}{\Delta NO_x}$$ to avoid double counting. This was also applied to the ship

scenarios where the fuel S content change scenarios also include a PPM change to be consistent with emission inventory assumptions made in other studies.

A check was carried out to see if the model total $PM_{2.5}$ response was the same as the model primary $PM_{2.5}$ response to a change in primary $PM_{2.5}$ emission. Chimère was the only model in which small differences were found. The scenarios described here[8] for a pure $PPM_{2.5}$ change (as oppose to a joint NO_x, $PPM_{2.5}$ change) were analysed on the basis of a $PM_{2.5}$ response. Chimère results would be very slightly different if the $PPM_{2.5}$ response had been used.

We note also that secondary $PM_{2.5}$ is not necessarily equal to the total secondary inorganic fraction as some models can promote secondary particles to a size range greater than $PM_{2.5}$. This is true for nitrates in the EMEP model and for all secondary inorganic aerosol in the Chimère model.

The strength of the Euro Delta studies is that each of the participating models has been independently developed, with different approaches have been taken for the many sub-models that comprise the overall model. These can be quite basic differences, such as the partitioning of the atmosphere into layers and the choice of layer thickness, or refinements such as amended reaction rate coefficients used in otherwise similar chemical sub-models.

It is therefore expected that models produce different results. A previous study to this, ED I, (Vautard et al., 2006; van Loon et al., 2007; Schaap et al., 2008) looked in detail at the variation in model predictions about a model ensemble and discussed modelling. In this summary report we focus on consistency in the trend response and, save in one or two places where modelled differences stand out, do not address model-to-model variations.

A key finding overall is that the models, despite their different formulations, do give very similar results.

The structure of this report section is as follows. We first examine land-based scenarios on an emitted pollutant basis for each of the countries in which the emission change was made. Results are presented on both a population weighted and a non-population weighted basis to give some indication of how population distribution may influence the results. It is not possible in this brief report to describe the detailed effect that each country emission has on all of its neighbours. We therefore look at the impact of the change across all countries (including the country where the changes are made) and the impact on the country itself.

First we examine the response of $PM_{2.5}$ which is influenced by emissions of SO_2, NO_x, NH_3 and primary $PM_{2.5}$. Then we look at the response of SOMO35 which is influenced by NO_x and VOC emissions. The deposition of oxidised Sulphur and of oxidised Nitrogen is then examined. For completeness the reduced nitrogen results are also presented but, as agriculture is the overwhelming source of ammonia there is no useful sectoral information.

We then look at the on-land impacts of emission changes in the Mediterranean Sea. Finally the potency of on-land and at-sea emission changes are compared.

[8] Scenarios 5, 8, 16, 19, 28, 31, 44, 47

4.1 Evaluation of sectoral approaches

In each of the following cases we compare the change in end point per unit change in emission in several ways:

> Each example[9] has an "ALL" scenario. This which corresponds to the way that source-receptor relationships are built for policy use. The country emissions of a pollutant are reduced with the change applied proportionately to each emitting sector. The all scenario always appears as the left-most column in the bar-charts.
>
> Next we have one or more cases where the emission is reduced for a single sector only. If the effectiveness obtained is the same as the 'ALL' scenario then an emission control on this sector would be as effective as expected by a current policy assumption. If the sector efficiency is less than the 'ALL' scenario then emission control on that sector would deliver less than expected by current policy. If the sector efficiency is greater than the 'ALL' scenario then emission control on that sector would deliver more than expected by current policy methods.
>
> In some cases the single scenario changes are accompanied by a combined scenario. Here the cumulative effect of all the single sector changes are run together. The total emission change is numerically the same as that in the ALL scenario. This is a test both of independence and whether other sectors (present in the ALL scenario but not in the combined scenario) are important.
>
> Lastly for some cases a linearity check has been carried out. The linearity check calculations (right hand columns) in the charts represent response to a smaller emission reduction than the prime scenarios.

All emission changes are given in Table 1. Where emission changes are given across two sectors (e.g. 1 & 4) it is generally the case in combined scenarios that one of these sectors has a dominant emission of the pollutant.

[9] The exception is NH_3 emissions. Because these are overwhelmingly from the Agricultural sector there is no difference between the policy approach and the sectoral approach for this pollutant.

4.1.1 Response of $PM_{2.5}$ to SO_2 emission changes

The effect of reducing SO_2 emissions independently in France, Germany, Spain and the United Kingdom on the fine particulate matter concentration across the countries in the studied domain is shown in Figure 1 and in Figure 2. The domain is here labelled EU-25 for consistency with the direct output of the toolkit. Although this is not exactly the same as the full EU domain as described in the Introduction the results do reflect the contributions each country emission makes to Europe. The effect of the emission reductions on concentrations within the emitting country is shown in Figure 3 and in Figure 4. Impacts on the nearest neighbouring countries are intermediate in value.

$PM_{2.5}$ comprises sulphate, nitrate, ammonium and primary particulate material and so the changes seen are largely manifested through the sulphate contribution although, some extra nitrate particles can be formed where ammonia is in excess. Results are normalised with respect to the SO_2 emission reduction in each scenario to have units of $ng/m^3/kt$.

There are two figures for each case. In the first (Figure 1, Figure 3) the concentrations are population weighted to reflect that the concern of current policy is the potential adverse health effects of $PM_{2.5}$. The second (Figure 2, Figure 4) has no weighting applied. The difference between the two indicates the degree of correlation between population and emission impacts. It is important to note that we have not applied an urban increment in $PM_{2.5}$ to account for city sources.

In each chart in Figure 1 to Figure 4 the first bar represents the effect of making the emission change across all sectors and in proportion to the emission in that sector. This represents the present policy assumption of what happens when a national emission total is changed. The next bar shows the effect of making the emission reduction in SNAP sector 1. For consistency with Table 1 this is labelled as sectors 1 & 4 but the SO_2 reduction occurs in sector 1 (VOC reductions are made in sector 4 for this combined scenario). The next bar shows the effect of making changes in emissions in sector 3. (labelled 3&6). For Germany the effect of combining the scenario reductions in sectors 1 & 3 is calculated and a linearity check is included for both the all scenario and the sector 1 reductions. For Spain a reduction is made on sector 8 (labelled as 7 and 8) because there are greater SO_2 emissions in this country from off-road transport sources than in the other countries investigated.

Figure 1 shows that, in terms of effect on the EU-25, emission changes in Germany have a greater effect than those in France and the United Kingdom (about equal) with the effect of those in Spain being least. This reflects the proximity of the (emission sources within) each country to neighbours in Europe. The sectoral results show an overall trend for the effectiveness of reductions in sector 1 to be less than reductions in sector 3 and in the all scenario. The extent of this differentiation is country and model dependent. It is greatest for Germany and least for Spain. Models 3 and 5 show the least sectoral effect. Physically the difference between sector 3 and sector 1 emissions is emission height; more of the sector 3 emissions are emitted at low level than for sector 1 which is dominated by high level sources. The distribution of emissions by height is given in Appendix B.5.

The population weighted efficiencies are greater than the non-population weighted efficiencies shown in Figure 2 for Germany and for the UK, less but more similar for

France and quite similar for Spain. This shows that population distribution can be a strongly influencing factor in selecting policy measures.

The ratio of the effectiveness of measures on individual sectors for Model 3 is shown in Table 2 for the population weighted results. Sector 1 controls are 26% less effective in France, 14% in the UK and Germany and equal to the All scenario in the UK.

	Sector efficiency /All scenario		
	1	3	8
FR	0.74	1.06	-
DE	0.86	1.03	-
ES	1.01	1.03	1.06
UK	0.86	0.96	-

Table 2. Relative Sectoral Efficiencies, PM in Europe from SO_2 reduction, Model 3

The response on the emission reductions to concentrations in each emission country itself is much larger than that averaged over the EU-25. Results are shown in Figure 3 and in Figure 4 for the population and non-population weighted results respectively. The sectoral sensitivity increases. The effectiveness of Sector 1 compared to the all scenario falls to 49% in France and sector 1 controls are 25% less effective in each of Germany, Spain and the UK. Sector 3 controls are now slightly less effective than the all scenario in France, Germany and the UK. In Spain sector 8 controls are more effective than the all scenario by 30%.

	Sector efficiency /All scenario		
	1	3	8
FR	0.49	0.86	-
DE	0.76	0.88	-
ES	0.76	0.94	1.30
UK	0.75	0.82	-

Table 3. Relative Sectoral Efficiencies, PM in France, Germany, Spain and the United Kingdom from SO_2 reduction, Model 3.

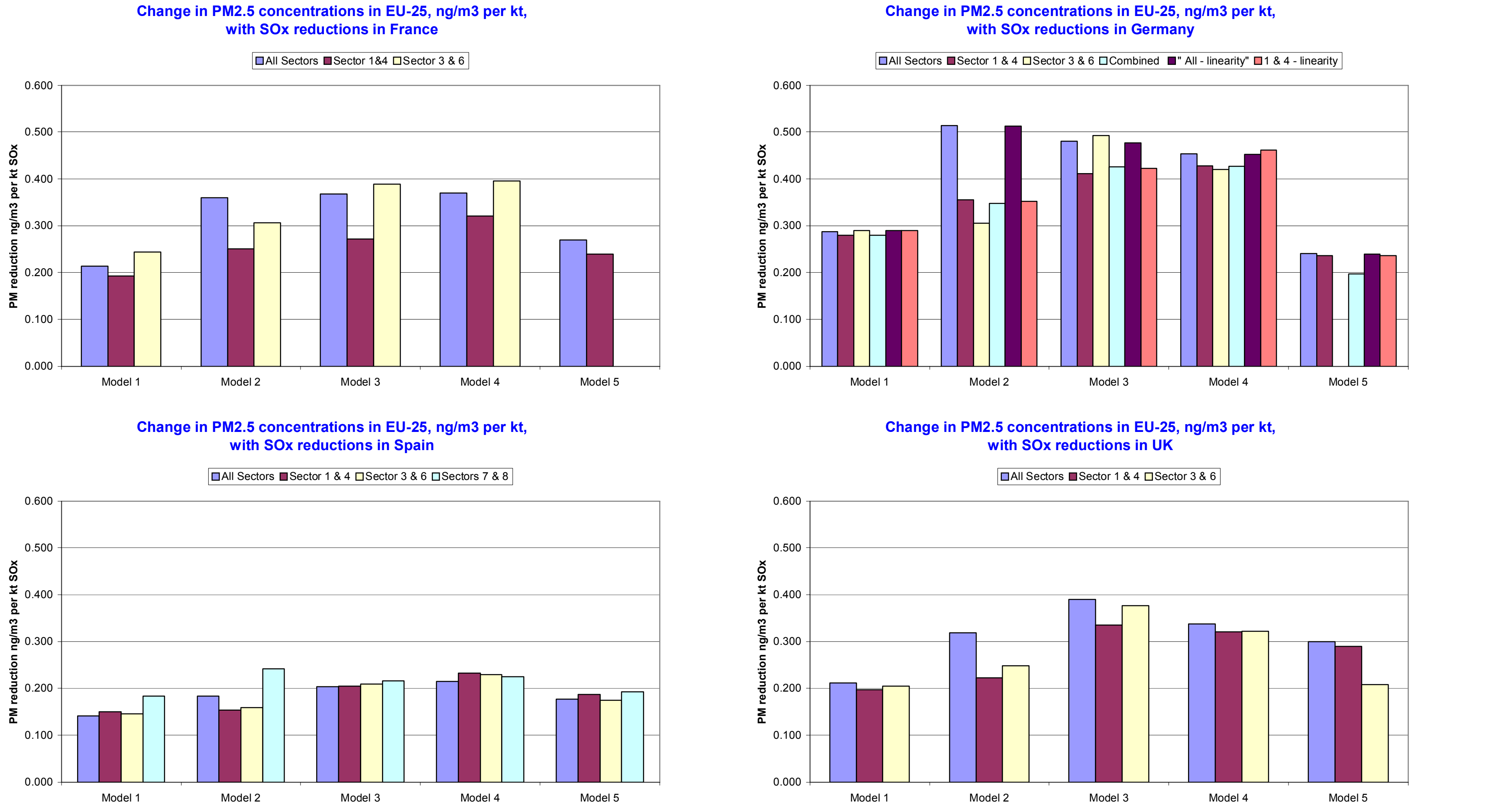


Figure 1. Effect of SO_2 emission reductions in France, Germany, Spain and UK on secondary particulate concentrations. Impacts shown are country to whole EU-25 (including the country of emission) and are population weighted.

Figure 2. Effect of SO_2 emission reductions in France, Germany, Spain and UK on secondary particulate concentrations. Impacts shown are country to whole EU-25 (including the country of emission).

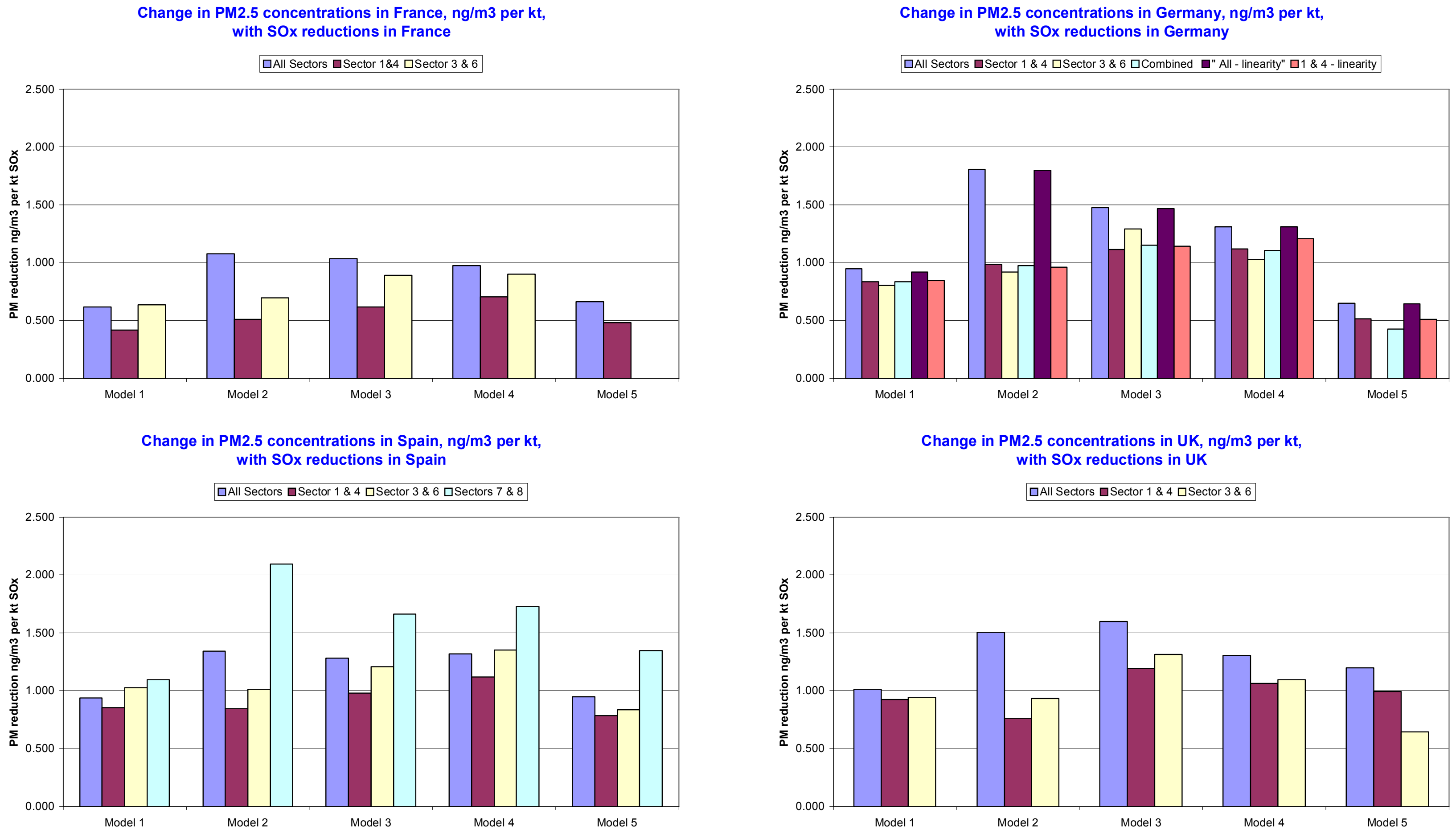


Figure 3. Effect of SO_2 emission reductions in France, Germany, Spain and UK on secondary particulate concentrations. Impacts shown are for the countries in which the emission reductions took place and results are population weighted

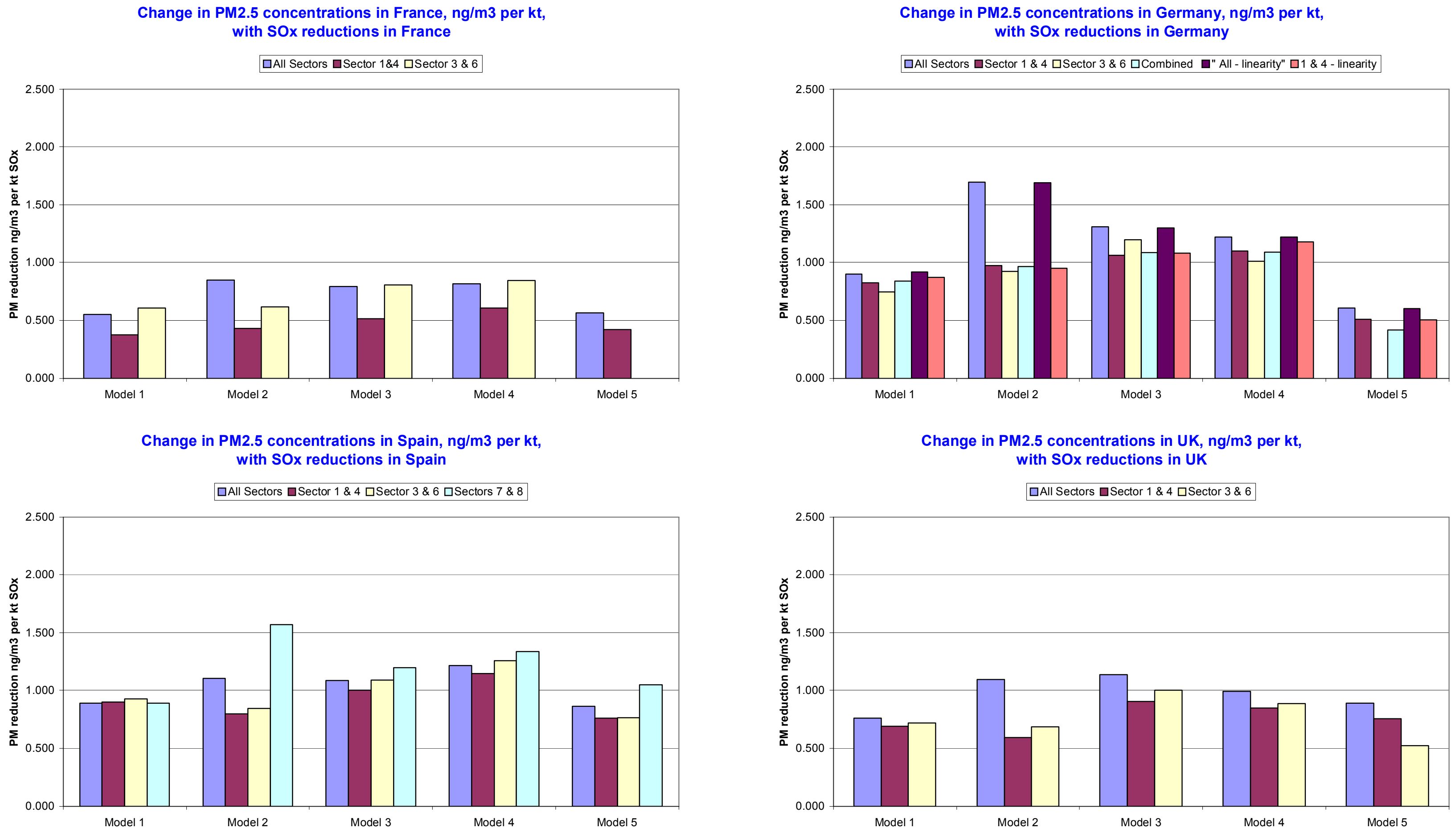


Figure 4. Effect of SO_2 emission reductions in France, Germany, Spain and UK on secondary particulate concentrations. Impacts shown are for the countries in which the emission reductions took place.

4.1.2 Response of $PM_{2.5}$ to NO_x emission changes

The effect of NO_x reductions on $PM_{2.5}$ concentrations is shown in Figure 5 (population weighted case) and Figure 6 (non weighted case) for the EU-25 wide impact and in Figure 7 (population weighted) and Figure 8 (non-weighted) for the effect in the emitting country. The reduction is mainly through the nitrate contribution.

The third bar in each chart is now the effect of a change in the transport sector (SNAP 7). The Model 5 results in the toolkit were unphysical (presumably a data processing error) in France and have been excluded.

Taking the EU wide impacts first. There is again a difference in overall response between countries with emission changes in Germany having the greatest transboundary effect on $PM_{2.5}$ concentrations. The models are consistent with sectoral trends in all countries. Sector 1 and sector 3 have lower response than the "all" scenario and sector 7 has a greater response. The population weighted responses are overall greater than the non-weighted responses and the differential between sector 7 and sector 1 increases when population is accounted for. The relative difference between sectors as predicted by model 3 is given in Table 4. France has the flattest response with sector 1 controls being ~ 9% less effective than the all scenario and transport sector ~ 5% more effective. The greatest spread is in Spain with sector 1 being ~ 35% less effective and transport ~ 15% more effective than the all scenario.

	sector efficiency/all sector efficiency		
	1	3	7
FR	0.91	0.87	1.05
DE	0.80	0.84	1.06
ES	0.65	0.93	1.15
UK	0.74	0.79	1.21

Table 4. Ratio of sector effectiveness to the all scenario effectiveness for model 3 for EU-25 wide impacts. Population weighted results.

The effectiveness of reductions on concentrations within the countries themselves is again larger as shown in Figure 7 for the population weighted response and in Figure 8 for the non-weighted results. Particularly marked is the difference between the sectoral effectiveness and the Spanish response is now numerically more similar to the other countries. The difference between the population weighted and the non-weighted results is very small and not readily discernable in Germany and in France.

	sector efficiency/all sector efficiency		
	1	3	7
FR	0.70	0.59	1.16
DE	0.69	0.77	1.14
ES	0.48	0.80	1.33
UK	0.55	0.66	1.44

Table 5. Ratio of sector effectiveness to the all scenario effectiveness for model 3 for country impacts. Population weighted results.

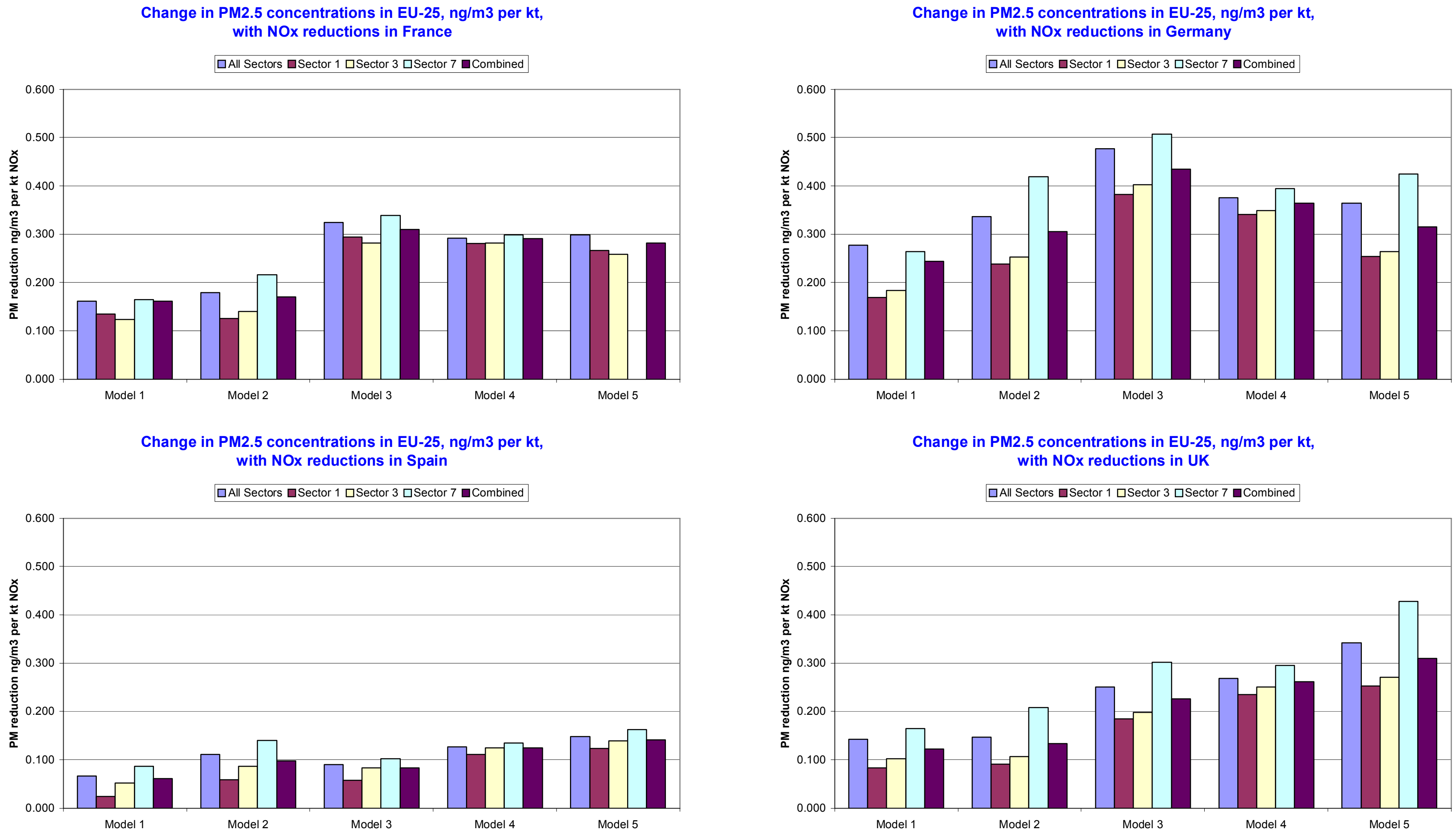


Figure 5. Effect of NO_x emission reductions in France, Germany, Spain and UK on secondary particulate concentrations. The Impacts shown are for the EU-25 and concentrations are population weighted.

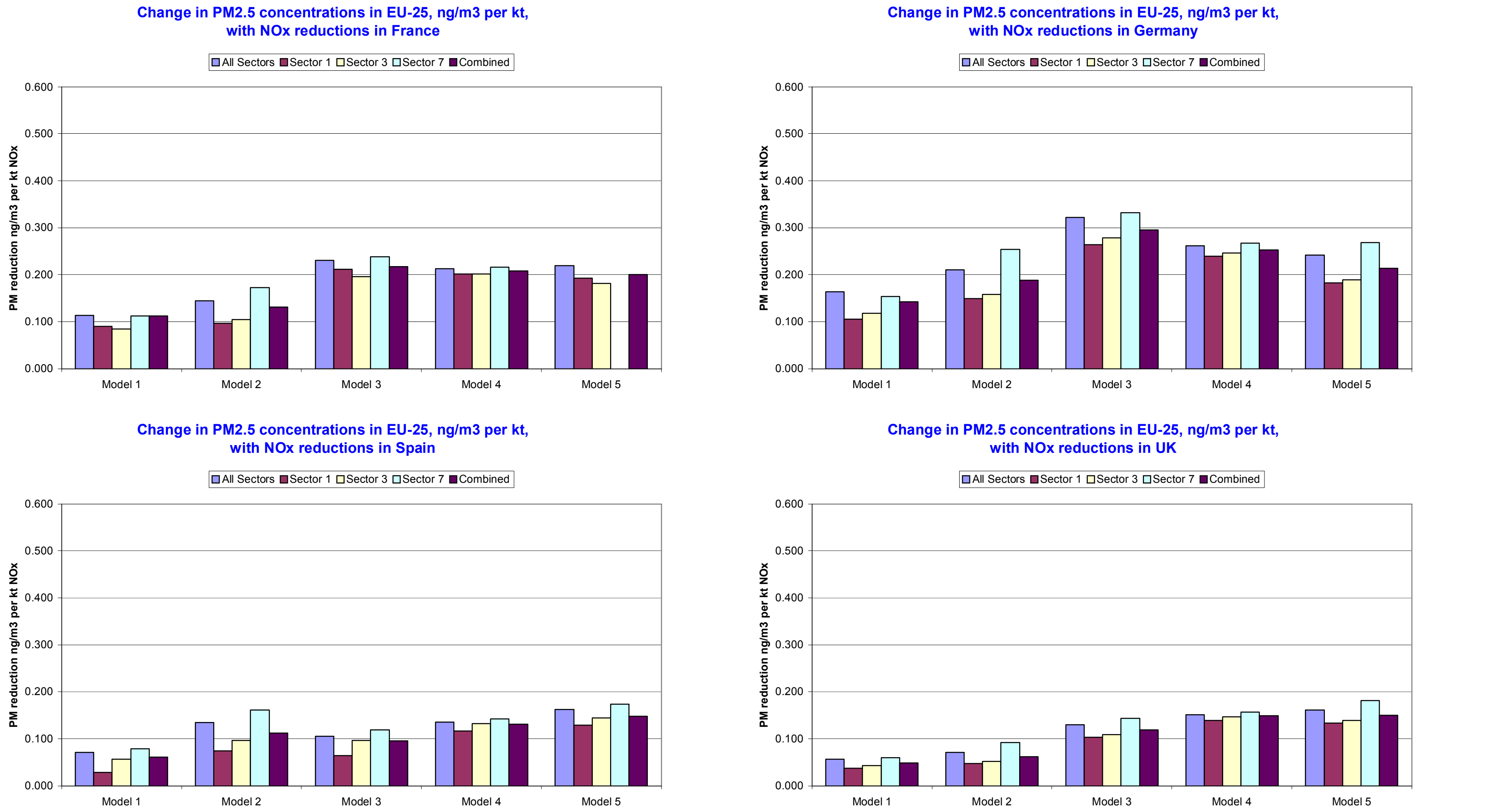


Figure 6. Effect of NO_x emission reductions in France, Germany, Spain and UK on secondary particulate concentrations. The Impacts shown are for the EU-25 and are not weighted.

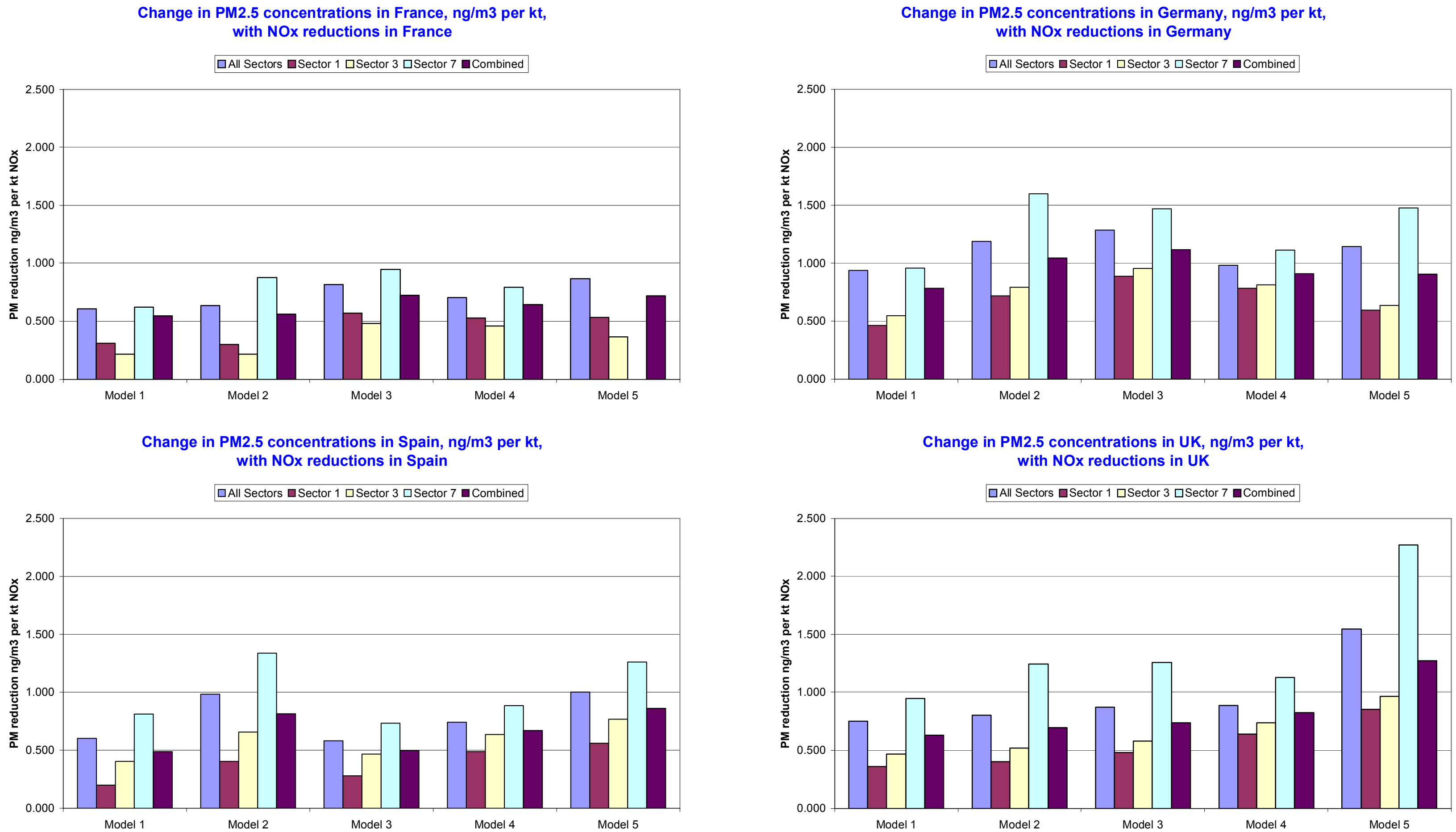


Figure 7. Effect of NO_x emission reductions in France, Germany, Spain and UK on secondary particulate concentrations. Impacts shown are for the countries in which the emission reductions took place and are population weighted.

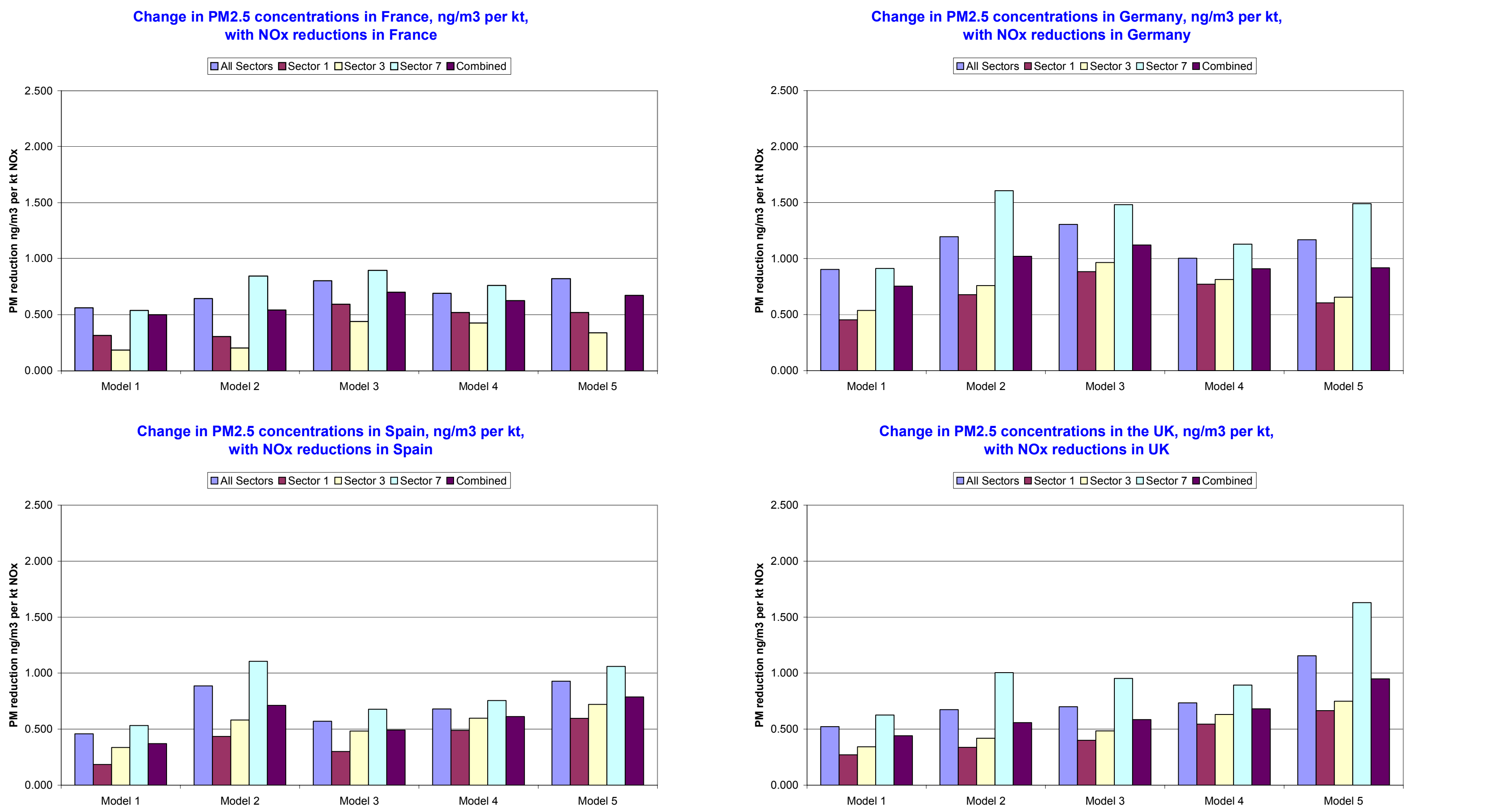


Figure 8. Effect of NO_x emission reductions in France, Germany, Spain and UK on secondary particulate concentrations. Impacts shown are for the countries in which the emission reductions took place and are not weighted.

Table 5 shows the ratio of effectiveness of the single sector to the all scenario reductions for model 3 using the population weighted results. It is clear that sector 7 has a larger effectiveness (14% in Germany rising to 44% in the UK) than the all scenario and sector 1 emissions are less effective (30% less in France to 52% less in Spain). If the effectiveness of sector 7 to sector 1 is taken the ratio is 1.66 in France and Germany increasing to 2.66 and 2.77 in UK and Spain respectively.

4.1.3 Response of $PM_{2.5}$ to ammonia emission changes

Figure 9 shows the response to ammonia emission changes. As only one sector, agriculture, is the dominant source there is no equivalent “all sectors” approach to ammonia reduction. The national and the EU-25 impacts are shown on the same figure.

The UK has by far the largest response to ammonia emission reductions and this is agreed by all of the models. The magnitude is a factor of 3. To check whether this is a feature of population weighting for a heavily populated country such as the UK the reduction potency was recalculated on the area average basis. Results are shown in Figure 10. On an area-average basis the amplitude of the signal is reduced in all the countries and slightly more in the UK than in the others but the overall country comparison is unchanged with the UK response being about a factor 2 higher than in the other countries.

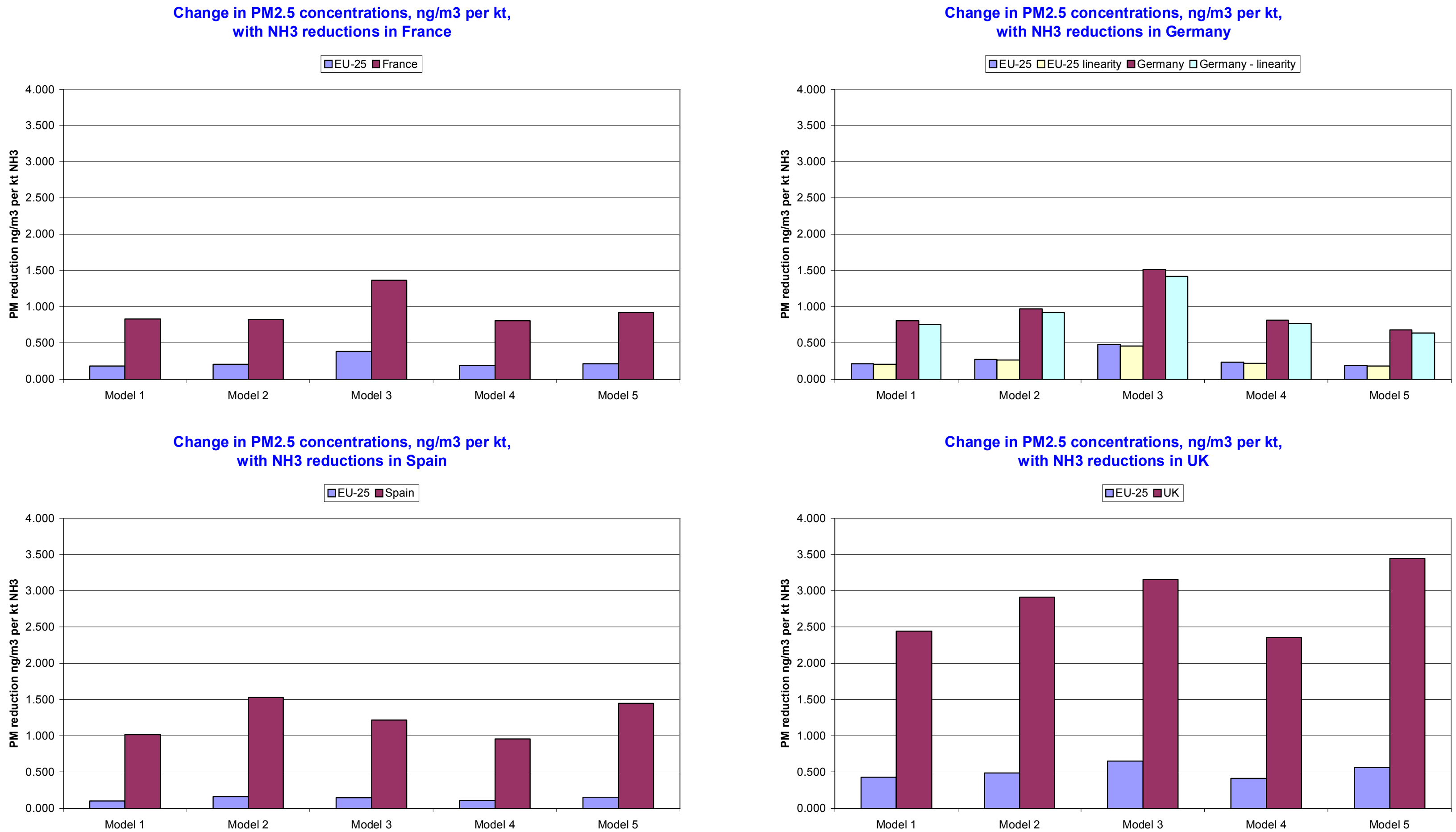


Figure 9. The effect of Ammonia reductions on secondary particulate concentrations in both the countries where emission reductions are made and on the EU-25. Results are population weighted.

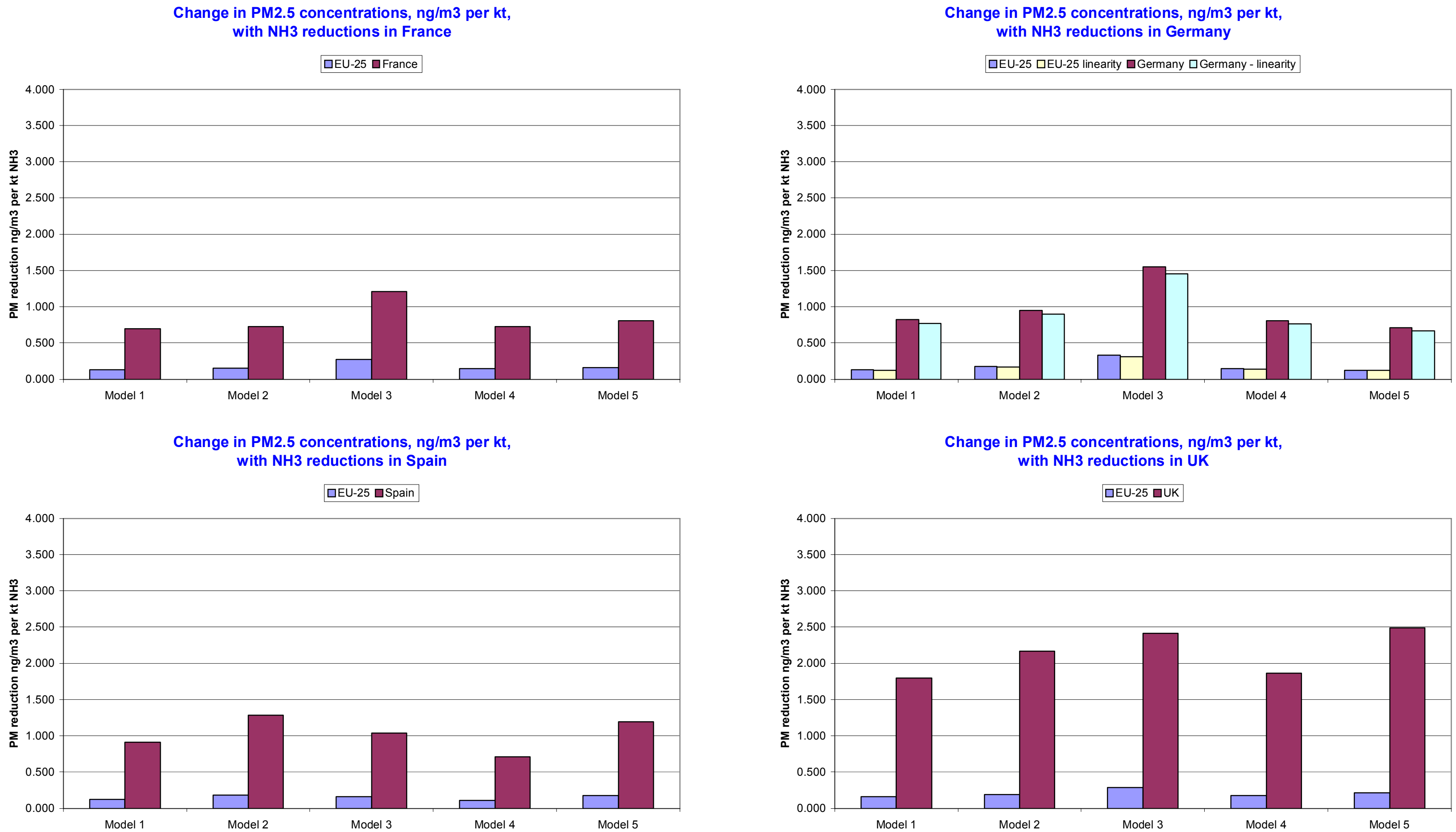


Figure 10. The effect of Ammonia reductions on secondary particulate concentrations in both the countries where emission reductions are made and on the EU-25. No population weighting has been applied.

4.1.4 Effect on $PM_{2.5}$ concentrations of reducing primary particle emissions

Reducing primary particle emissions directly has a much larger direct effect on concentrations but it must be remembered that overall emissions (in kt/a) are quite small compared to those of the precursors for secondary particles. Thus the overall total abatement potential more limited than for precursor emissions if the policy driver is to reduce all particles without regard to potential differences in health end-point.

Figure 11 shows the effect on the EU-25 of reducing emissions in each of the four countries. Several sectors contribute primary particles and so there are several bars on the graph. The results are population weighted and the corresponding unweighted values are given in Figure 12. The effect of population weighting is to increase the overall impacts (greater effectiveness of reduction) and to increase the difference between sectors. This reflects the importance of the close proximity of ground level sources to population. The population weighted results are described below.

There is greater variation between model responses to primary $PM_{2.5}$ emission changes compared with precursors. This reflects that the concentrations and emissions are more closely located so that differences in model assumptions (such as the height of the lowest layer in the model representation of the atmosphere) feed more directly into the response. Overall, however there is still a high degree of consistence and it is clear that ‘all’ scenario is not representative of the sector scenarios.

Of the individual sectors:

- Sector 1 is generally the least effective.
- Sectors 7 and 4 are generally the most effective. In Germany all models agree that sector 4 has the overall strongest response while in France and the UK it is sector 7.
- In Spain sector 2 is stronger than in the other countries. This sector represents non-industrial combustion and thus includes emissions from domestic heating.

The country own impacts follow exactly the same trends as for the EU-25 impacts, they are just larger in magnitude by about a factor of 6 across the board. They are shown in Figure 13 for the population weighted results and in Figure 14 for the non-weighted results.

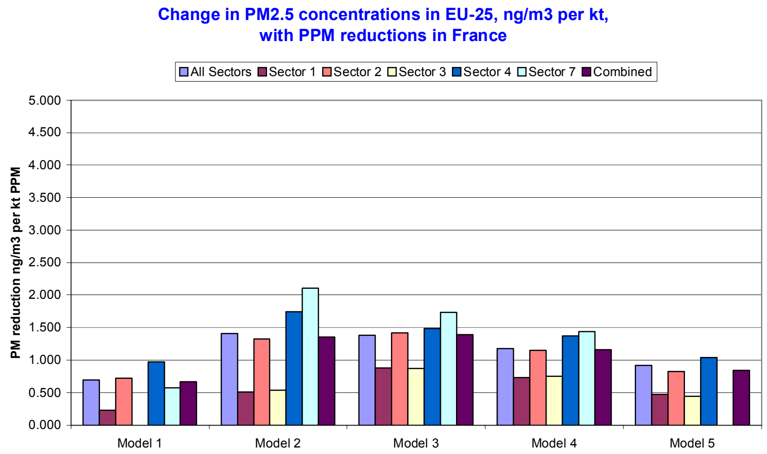
The ratio of effectiveness by sector for Model 3 is shown in Table 6 for the EU impact and in Table 7 for the impact in the emitting country. The values are for the population weighted results.

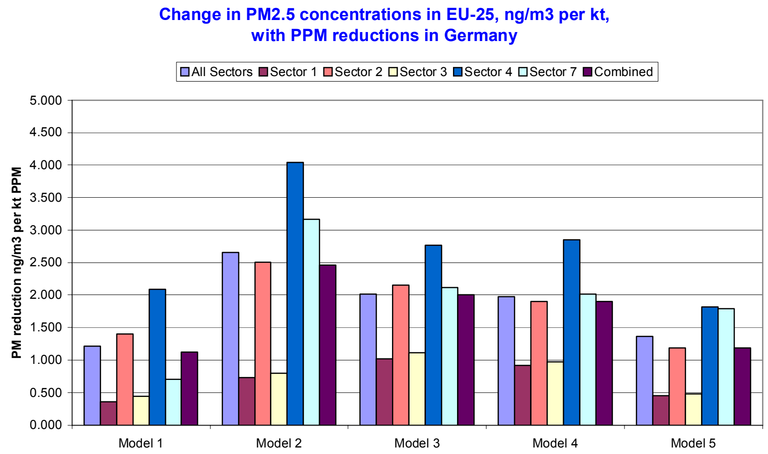
	sector efficiency/all sector efficiency				
	1	2	3	4	7
FR	0.64	1.03	0.63	1.08	1.26
DE	0.51	1.07	0.55	1.38	1.05
ES	0.39	1.78	0.52	0.84	1.09
UK	0.47	1.04	0.58	1.31	1.51

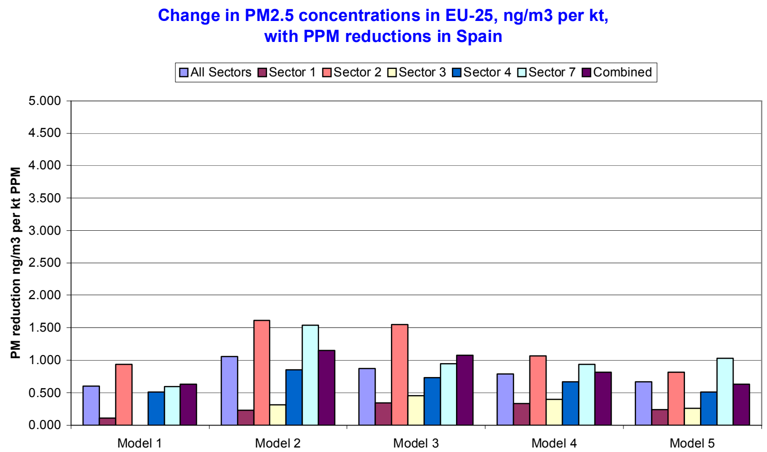
Table 6. Relative Effectiveness of sectoral emission reductions compared to the All scenario. Results are from Model 3 for the Country impact on the EU-25 and are population weighted

	sector efficiency/all sector efficiency				
	1	2	3	4	7
FR	0.40	1.02	0.40	1.08	1.47
DE	0.38	1.09	0.44	1.45	1.07
ES	0.26	1.96	0.41	0.80	1.12
UK	0.33	1.03	0.45	1.38	1.62

Table 7. Relative Effectiveness of sectoral emission reductions compared to the All scenario. Results are from Model 3 for the impact on emitting country and are population weighted







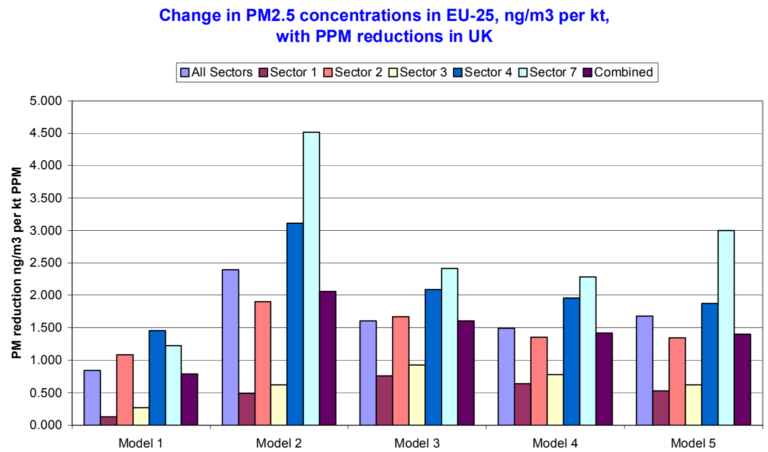


Figure 11. Effect of reducing primary $PM_{2.5}$ emissions on particle concentrations. Impacts shown are for the EU-25 and are population weighted.

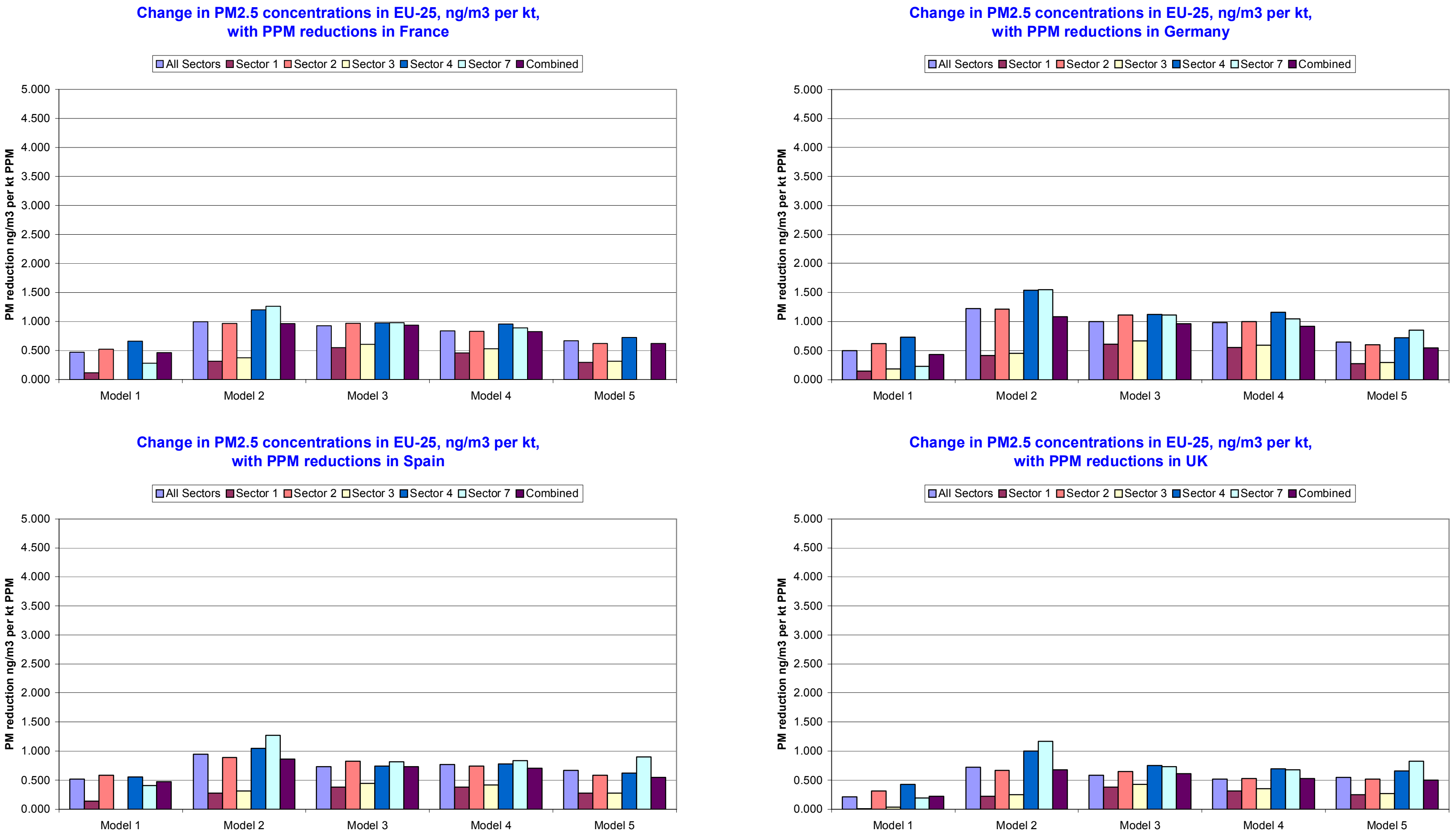


Figure 12. Effect of reducing primary $PM_{2.5}$ emissions on particle concentrations. Impacts shown are for the EU-25 and are not weighted.

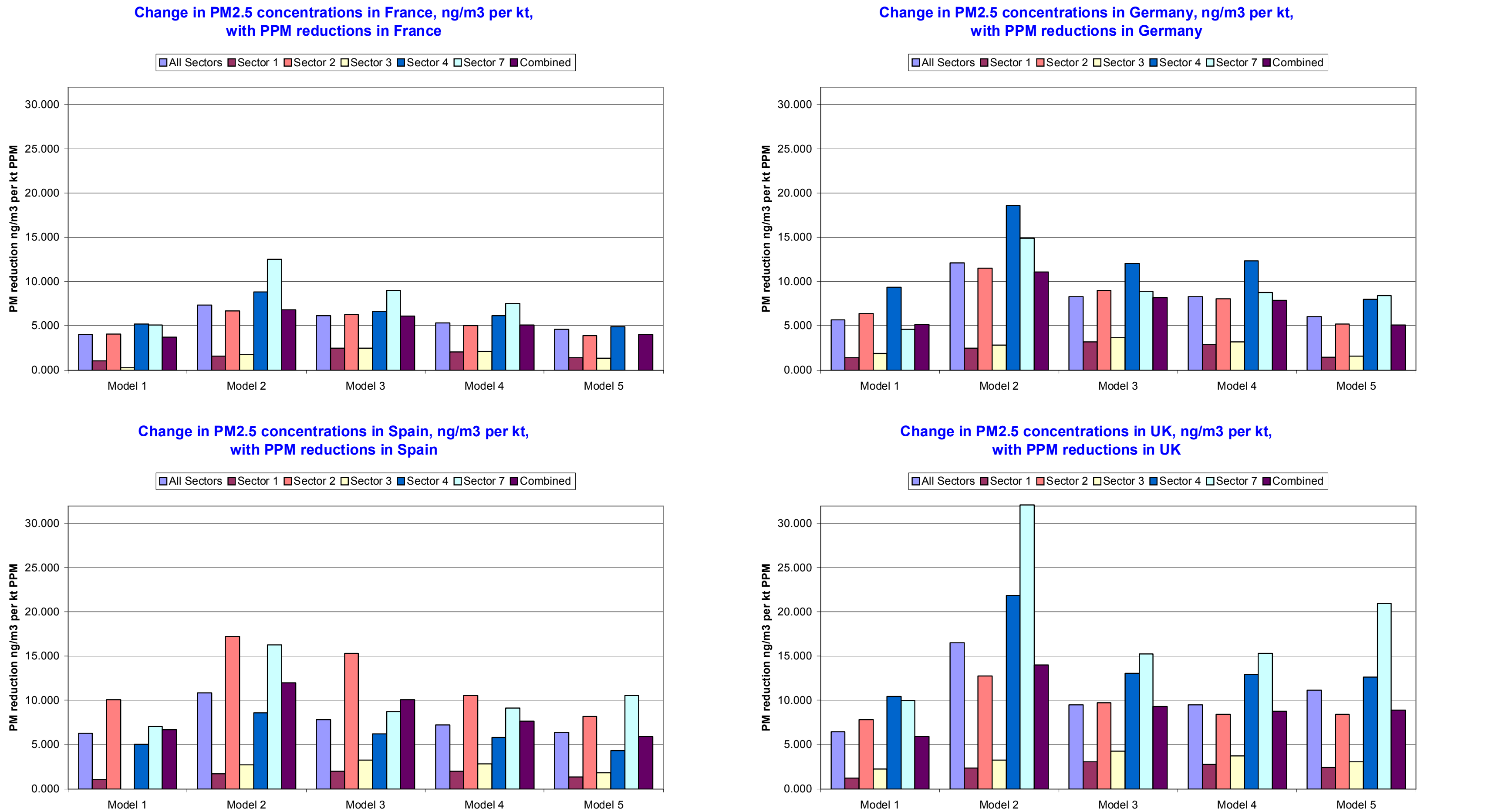


Figure 13. Effects of reducing primary particle emissions on $PM_{2.5}$ concentrations. Impacts shown are for the countries in which emission reductions take place and are population weighted.

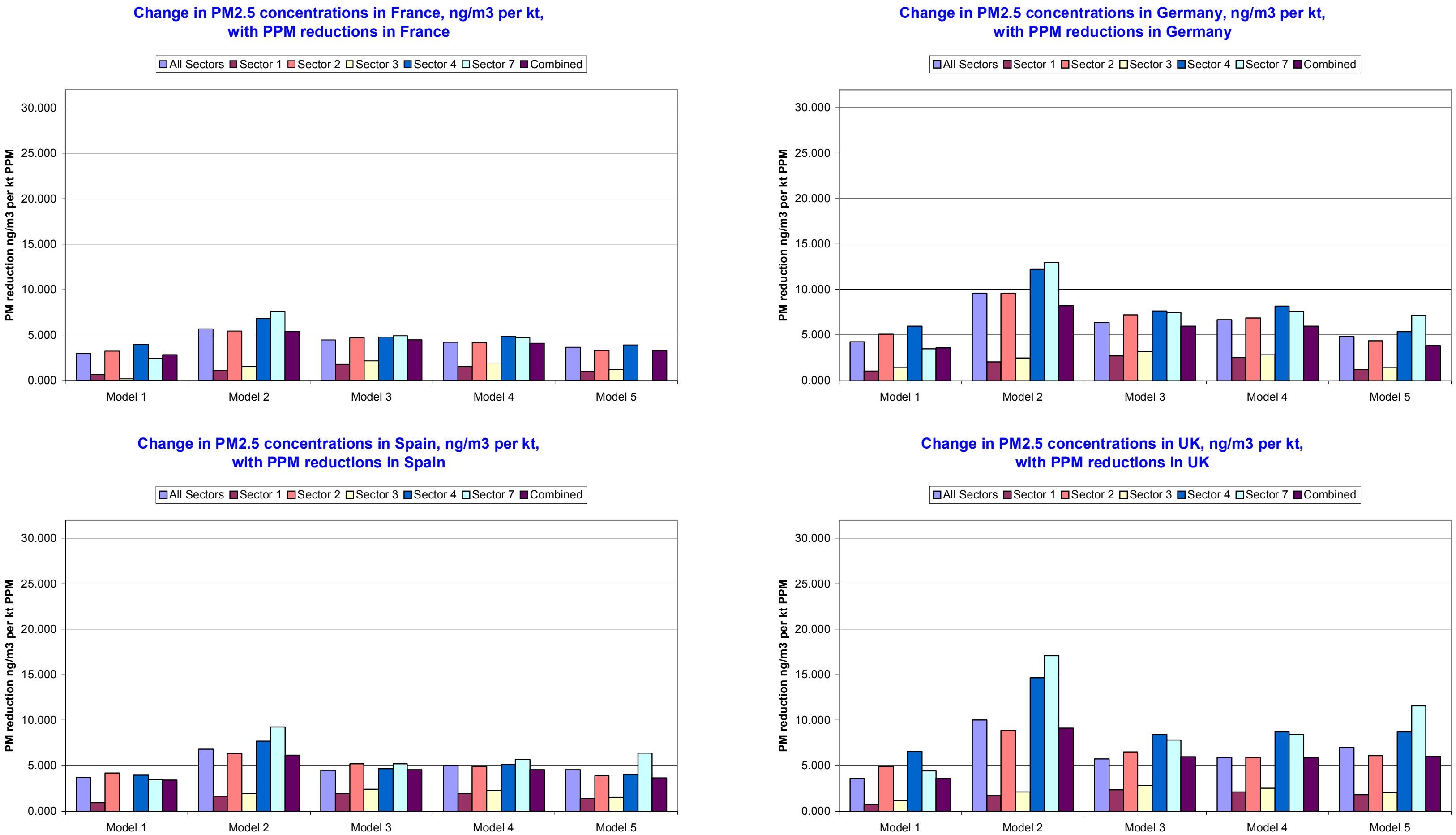


Figure 14. Effects of reducing primary particle emissions on $PM_{2.5}$ concentrations. Impacts shown are for the countries in which emission reductions take place and are not weighted.

4.1.5 Relative effectiveness of different emission reductions for $PM_{2.5}$

To give an overview of the reduction potential of the different pollutants the “all” scenario results have been compiled. Results on a population weighted basis are shown in Figure 15 for impact on the EU-25. The corresponding non-weighted results are shown in Figure 16. The results corresponding to the impacts on the country of emission are given in Figure 17 (population weighted) and Figure 18 (unweighted).

For presentation purposes the effectiveness of primary particle matter emissions have been plotted to a different scale to those of the precursor emissions and this scale is shown on the right-hand side of the graphs.

This comparison is only a part picture of the “true” reduction potential as in a policy context the amount of pollutant able to be reduced and the cost of that reduction have to be considered, and as we have seen, the emitting sector is another factor.

For overall impact on the EU-25 and using population weighting (Figure 15) , models 1- 4 rank reductions of SO_2 as being more or equal to reductions of NO_x in effectiveness. Model 5 has the opposite ordering. The effectiveness of NH_3 reductions in the UK is large compared with NH_3 reductions in other countries and much greater than the other precursor emissions. In the other countries the ammonia effectiveness is less than or similarly to NO_x taken overall. Removing the population weighting Figure 16 decreases the calculated effectiveness but not the ordering of the rankings. The weighting effect is largest in the UK and least in Spain where results are almost unchanged. Primary PM effectiveness is the most affected by a change in weighting.

For impact in the countries where emission reductions take place the rankings are very similar. The difference between population weighted (Figure 17) and unweighted (Figure 18) results is also smaller for primary PM and for ammonia. This reflects that these two pollutants are more short range in effect than NO_x and SO_x by virtue of their more rapid deposition.

Figure 15. Comparison of effect of reducing individual pollutants on $PM_{2.5}$ concentrations. Effects shown are for the whole EU-25. Primary PM2.5 is on the right hand scale, all other pollutants are on the left hand scale. Concentrations are population weighted.

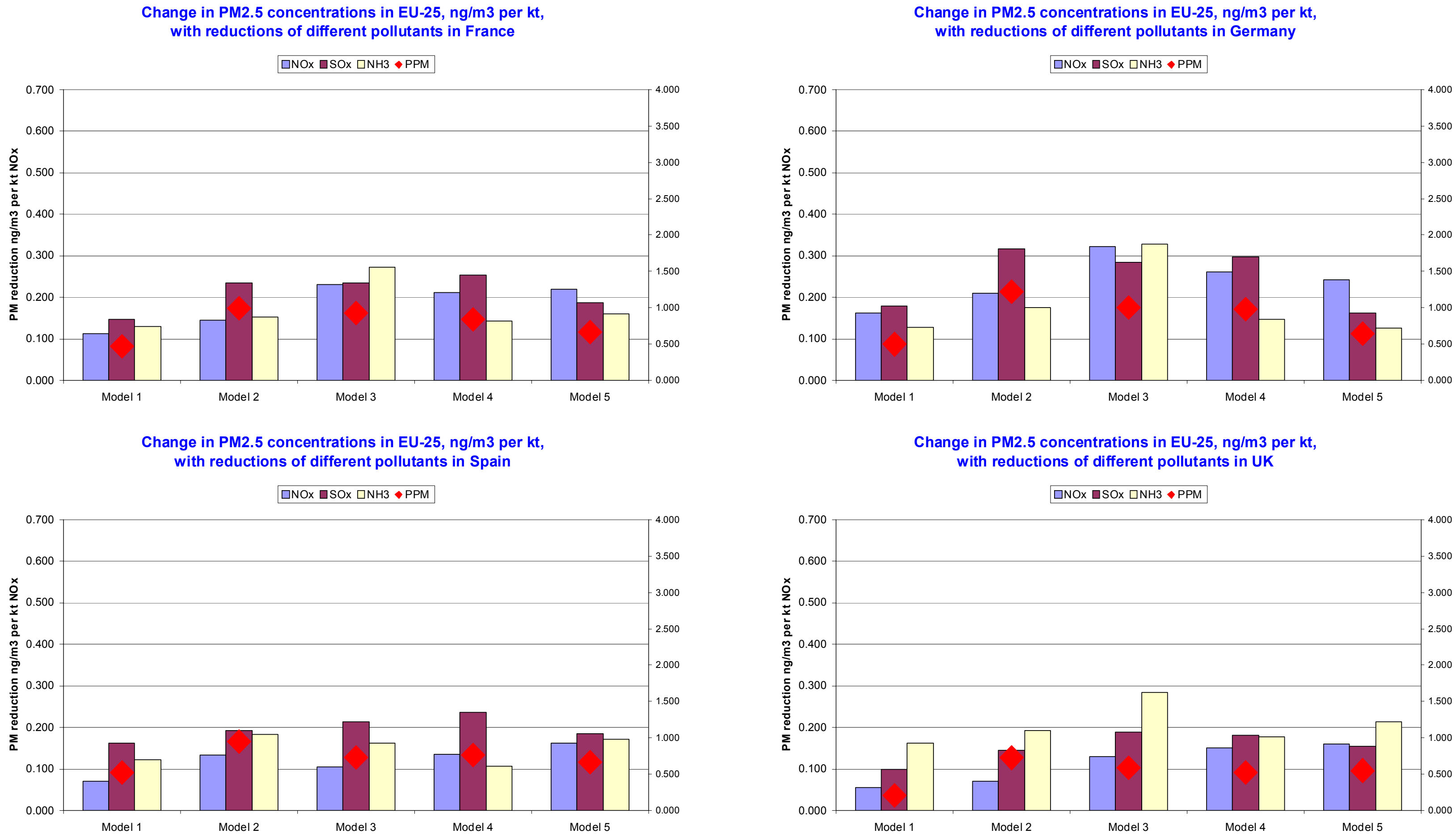


Figure 16. Comparison of effect of reducing individual pollutants on $PM_{2.5}$ concentrations. Effects shown are for the whole EU-25. Primary PM2.5 is on the right hand scale, all other pollutants are on the left hand scale. The results are unweighted.

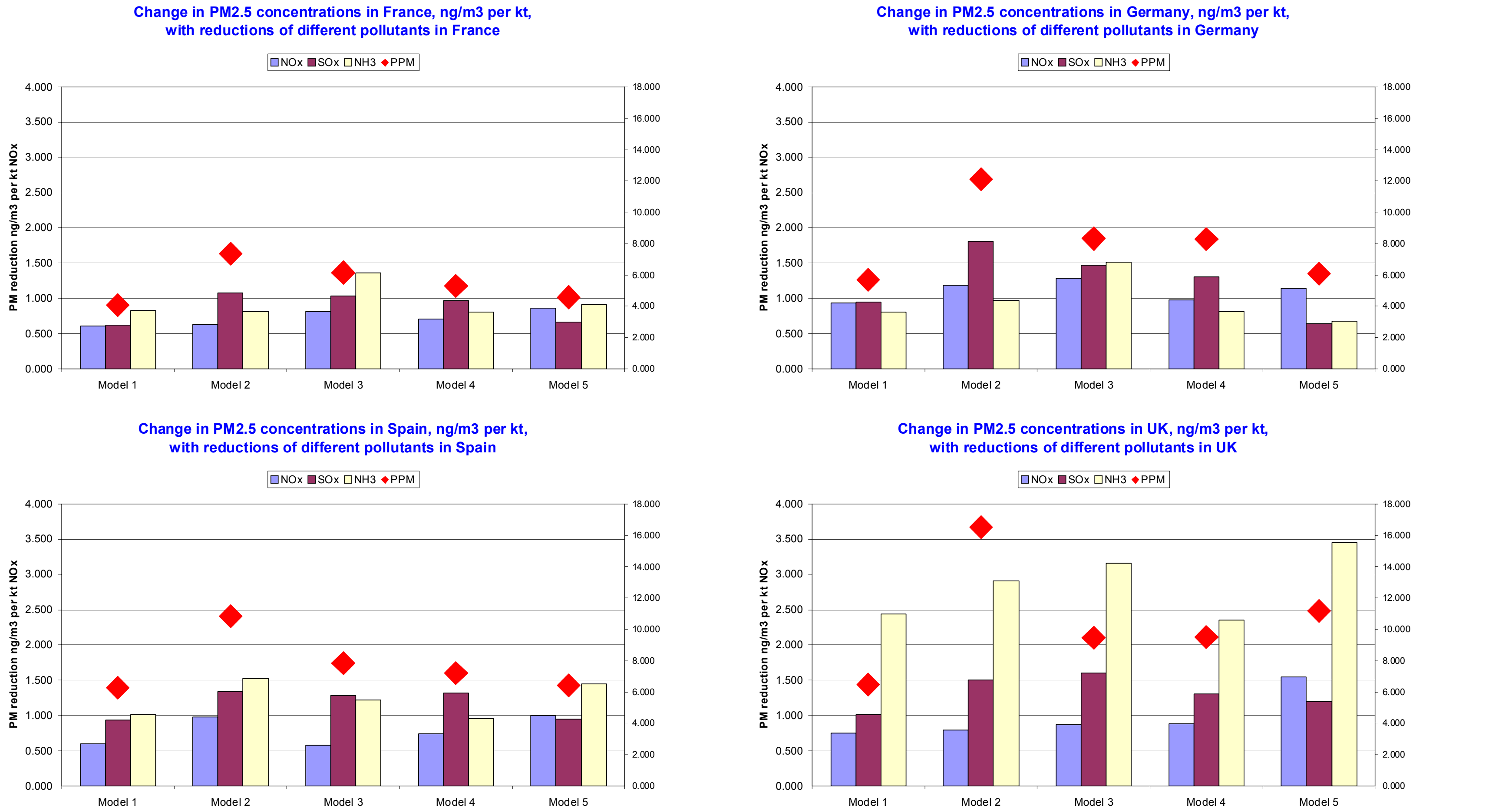


Figure 17. Comparison of effect of reducing individual pollutants on $PM_{2.5}$ concentrations. Effects shown are for the country in which the emission reduction is made. Primary PM2.5 is on the right hand scale, all other pollutants are on the left hand scale. Concentrations are population weighted.

Figure 18. Comparison of effect of reducing individual pollutants on $PM_{2.5}$ concentrations. Effects shown are for the country in which the emission reduction is made. Primary PM2.5 is on the right hand scale, all other pollutants are on the left hand scale. Concentrations are not weighted.

4.1.6 Effect of NO_x emission controls on SOMO35

Figure 19 shows the effect of reducing NO_x emissions on SOMO35 concentrations within the countries where the emission reductions take place.

The “all” scenario is compared with controls on sector 1, sector 3 and sector 7. The effect of combining the sector 1,3 and 7 controls is also shown.

The country differences are very large. All the models agree that the strongest overall response is in Spain and that the response in France and in Germany is similar. For UK models 1-4 predict that NO_x emissions can lead to a net increase in SOMO35 while model 5 predicts a reduction.

The sectoral response is varied. In general the sector 1 potency is less than that of the other sectors. This is most marked in France where the potency is about 3-5 times less than that of sector 7 which has the highest potency. In Germany there is very little difference between any of the sectors. In Spain the ordering is variable between models but there is little difference between sector 3 and sector 7 potency. In the UK, as above, the potency is small and varies between having a beneficial and a negative effect.

To test whether the population weighting had any effect on the ozone response to NO_x the potency was calculated without weights. This is a straightforward country area average. Results are shown in Figure 20 for impacts in the countries themselves and in Figure 22 for the effect on the EU-25. The small tendency of SOMO35 to increase in the UK is mitigated by taking the area average but otherwise the results are very similar.

4.1.7 Effect of VOC controls on SOMO35

There is some concern about our results for the effect of VOC controls on ozone.

It was assumed at the outset of the work that the coupling between SO_2 chemistry and ozone production would be much weaker than the effect of VOC’s on ozone. Furthermore, because SO_2 and VOC emission sources are not strongly correlated (and we do not study secondary organic aerosols) there was a mindset that the two pollutants could be treated as independent. As a consequence the SO_2 and VOC reduction scenarios were paired. No VOC only reduction scenarios were carried out to test the assumption of independence. It is therefore not possible to be entirely sure that the values reported below are all attributable to ozone. Furthermore, because ozone concentrations can go up or down in response to emission changes depending on several factors and with high spatial variability there may not be a consistent direction of effect on integrated measures such as country averaged SOMO35. The results in this next section should therefore be considered preliminary.

Figure 23 shows the effect of VOC controls on SOMO35. Compared with NO_x the potency per kt of VOC abated is very small. In France and In Germany the models agree that there is no strong sectoral effect although model 3 predicts virtually a nil potency for sectors 1&4. A unique scenario was run for Spain which included sectors 7 and 8 and this has the largest potency in that country. A sector 7 scenario was run in the UK and had the highest potency by a factor of more than 2 compared the (different) sector controls in the other countries.

The equivalent area averaged calculation is shown in Figure 24. The overall magnitude of the ozone changes is much reduced suggesting an important urban NO_x emission effect.

The effect of the sectoral changes in the countries on SOMO35 in the wider EU-25 is shown in Figure 25 for the population weighted case and in Figure 26 for the area averaged case. There is no difference in trend, to the country own impacts. The potency is reduced and the area averaged potency is less than the population weighted potency.

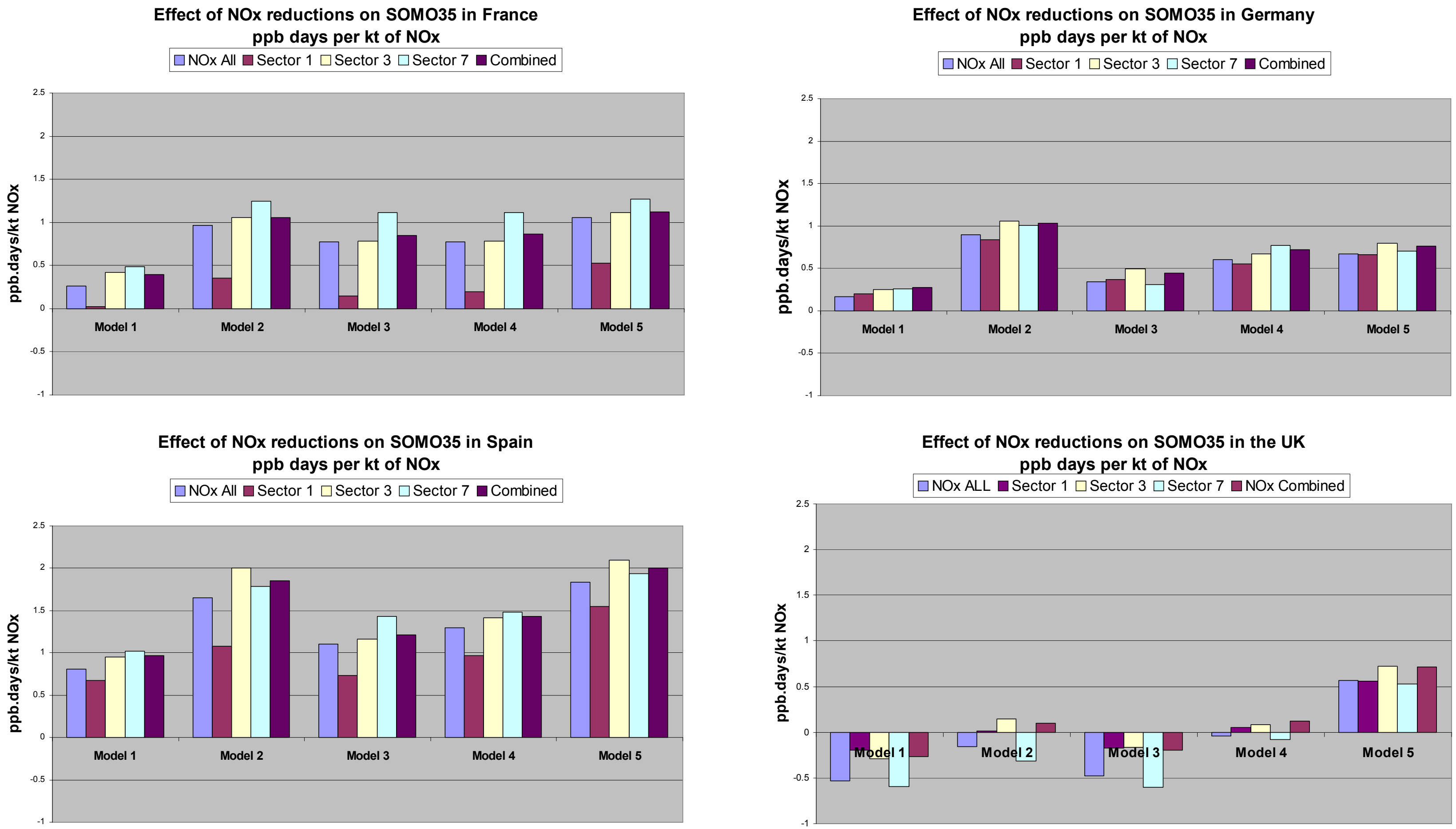


Figure 19. Population weighted values of SOMO35 showing effect of NOx reductions by sector in four countries

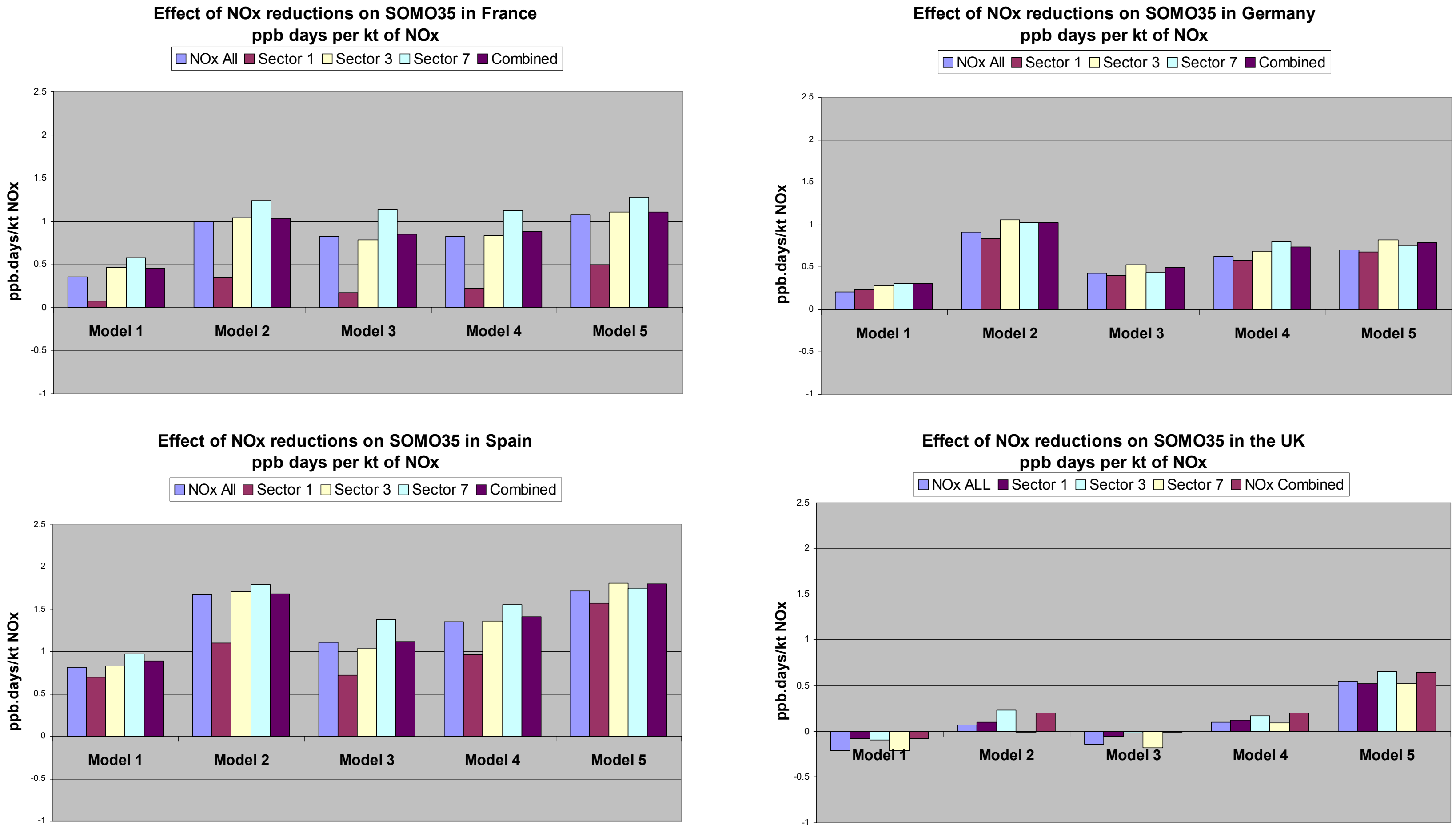


Figure 20. Area averaged values of SOMO35 showing effect of NOx reductions by sector in four countries

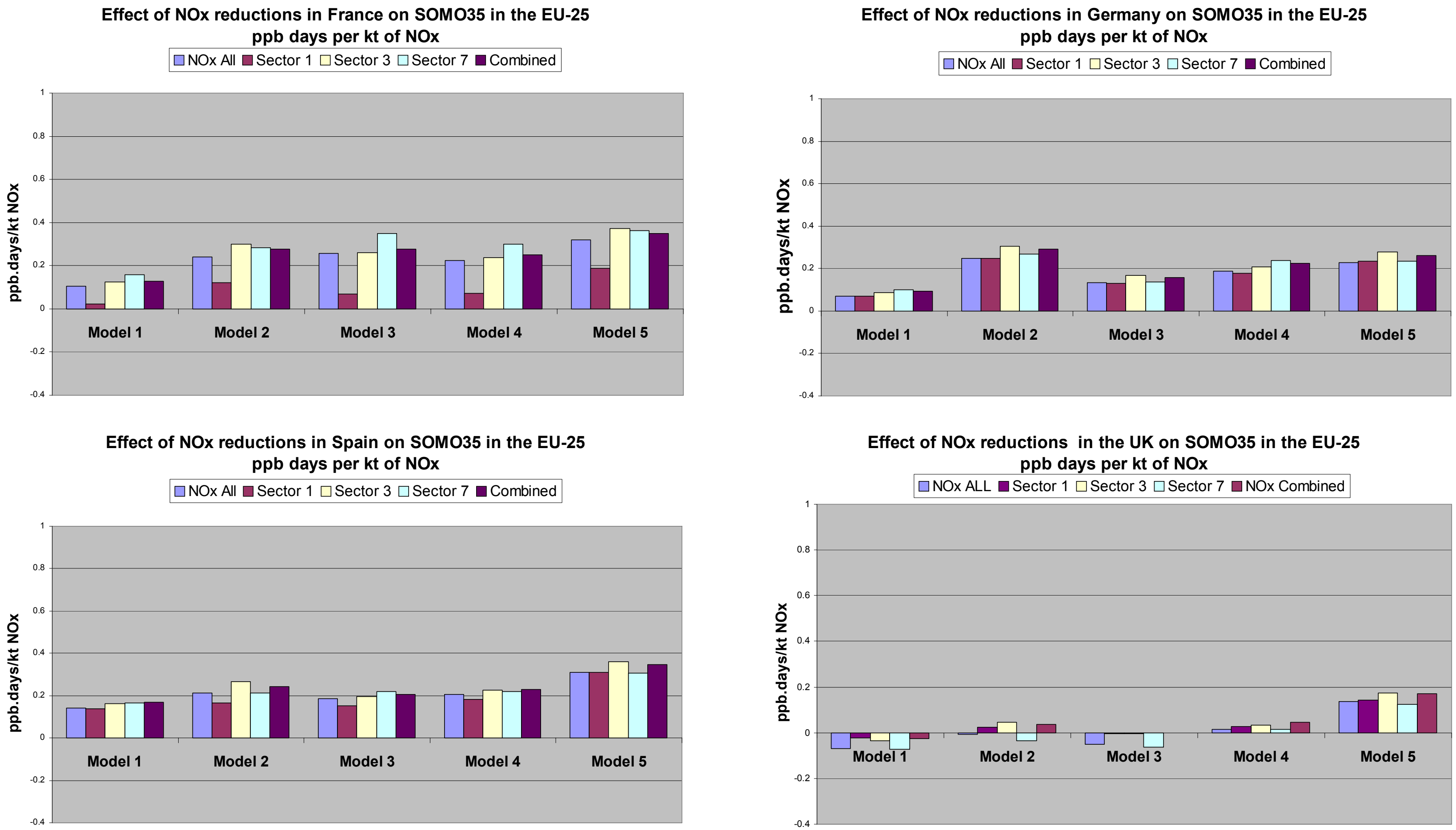


Figure 21. Population weighted change in SOMO35 in the EU-25 for a change in NOx emission in each of four countries

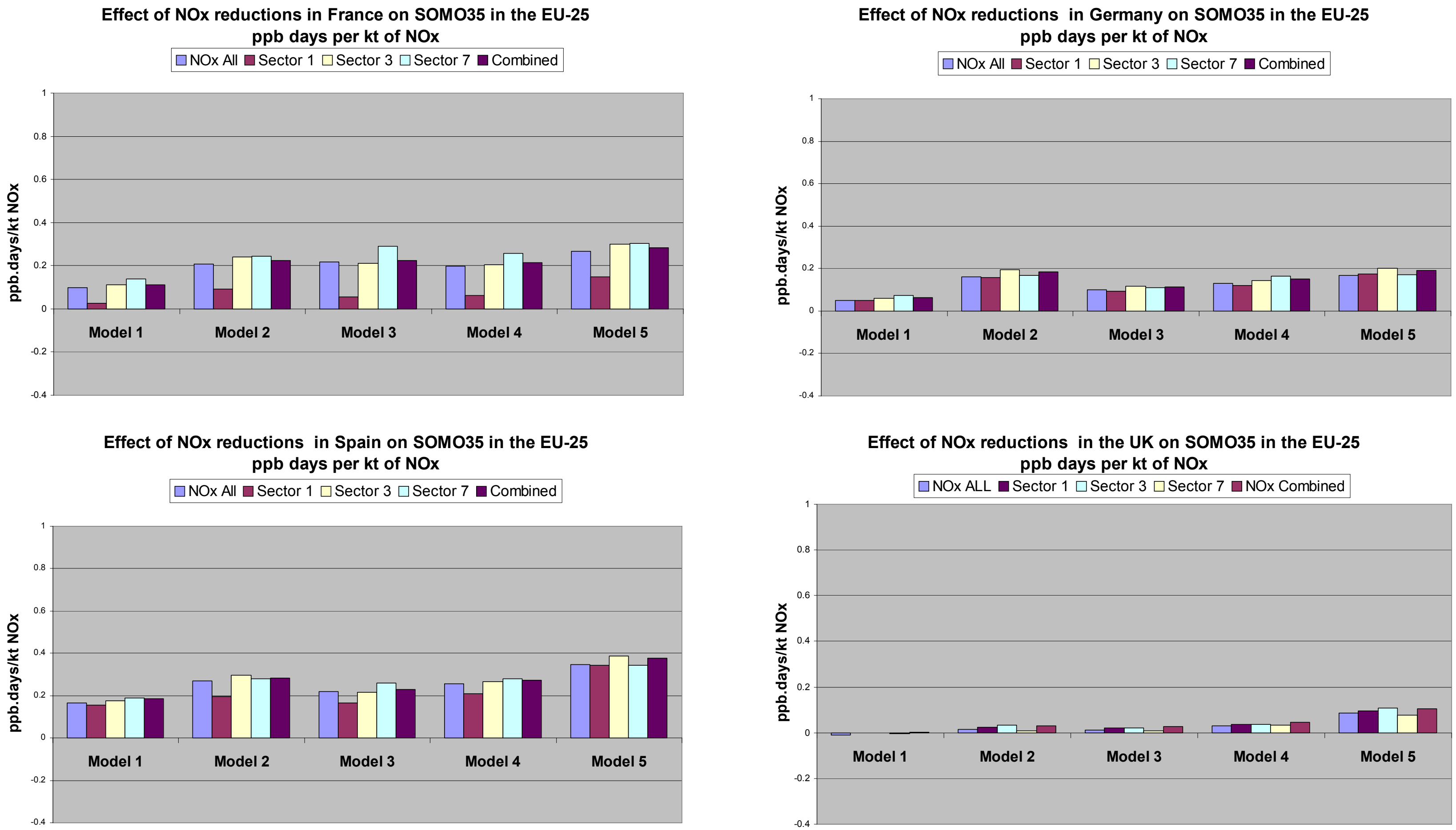


Figure 22. Change in SOMO35 in the EU-25 for a change in NOx emission in each of four countries

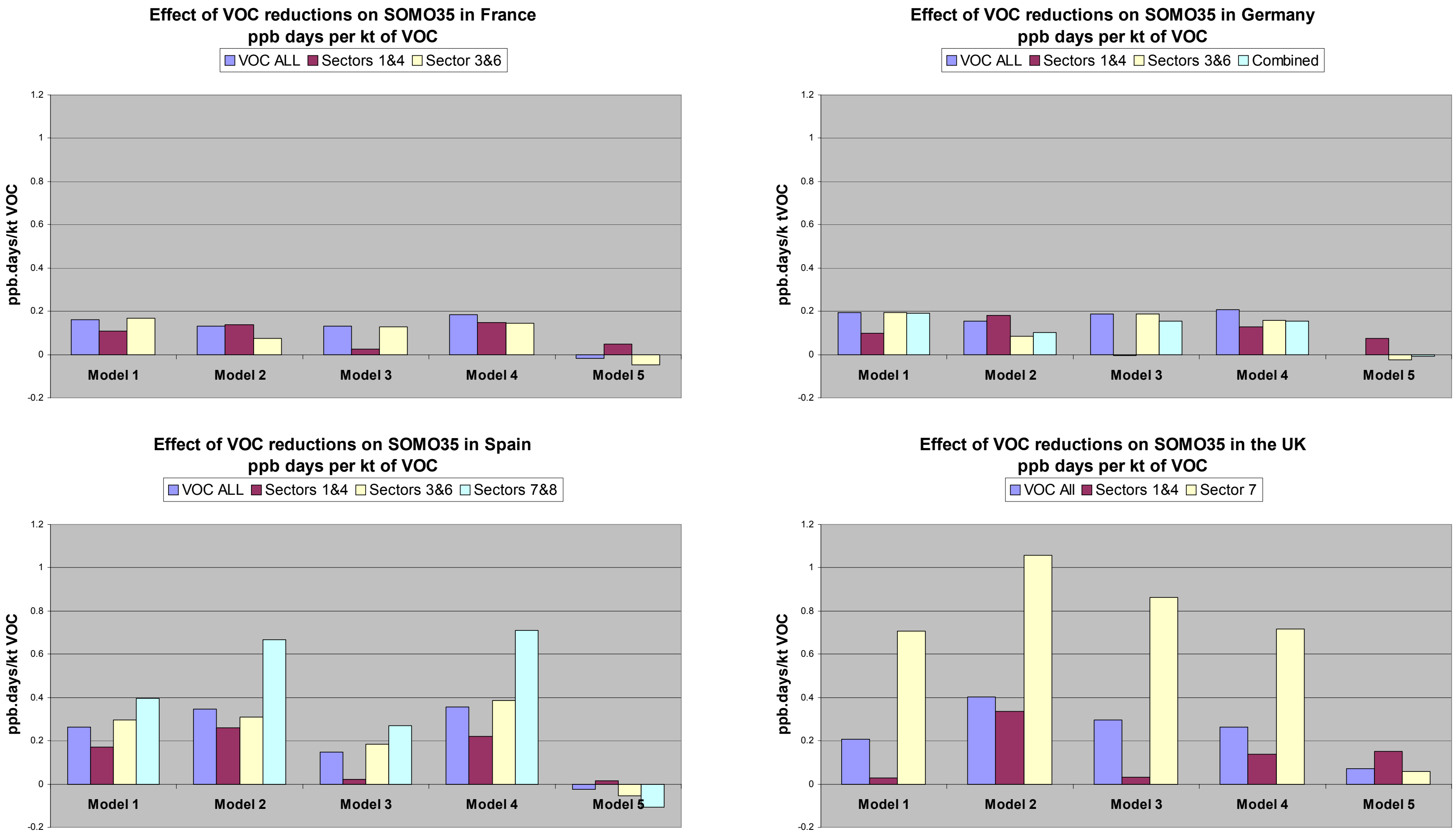


Figure 23. Effect of VOC emission reductions on population weighted SOMO35 in the countries where controls were applied.

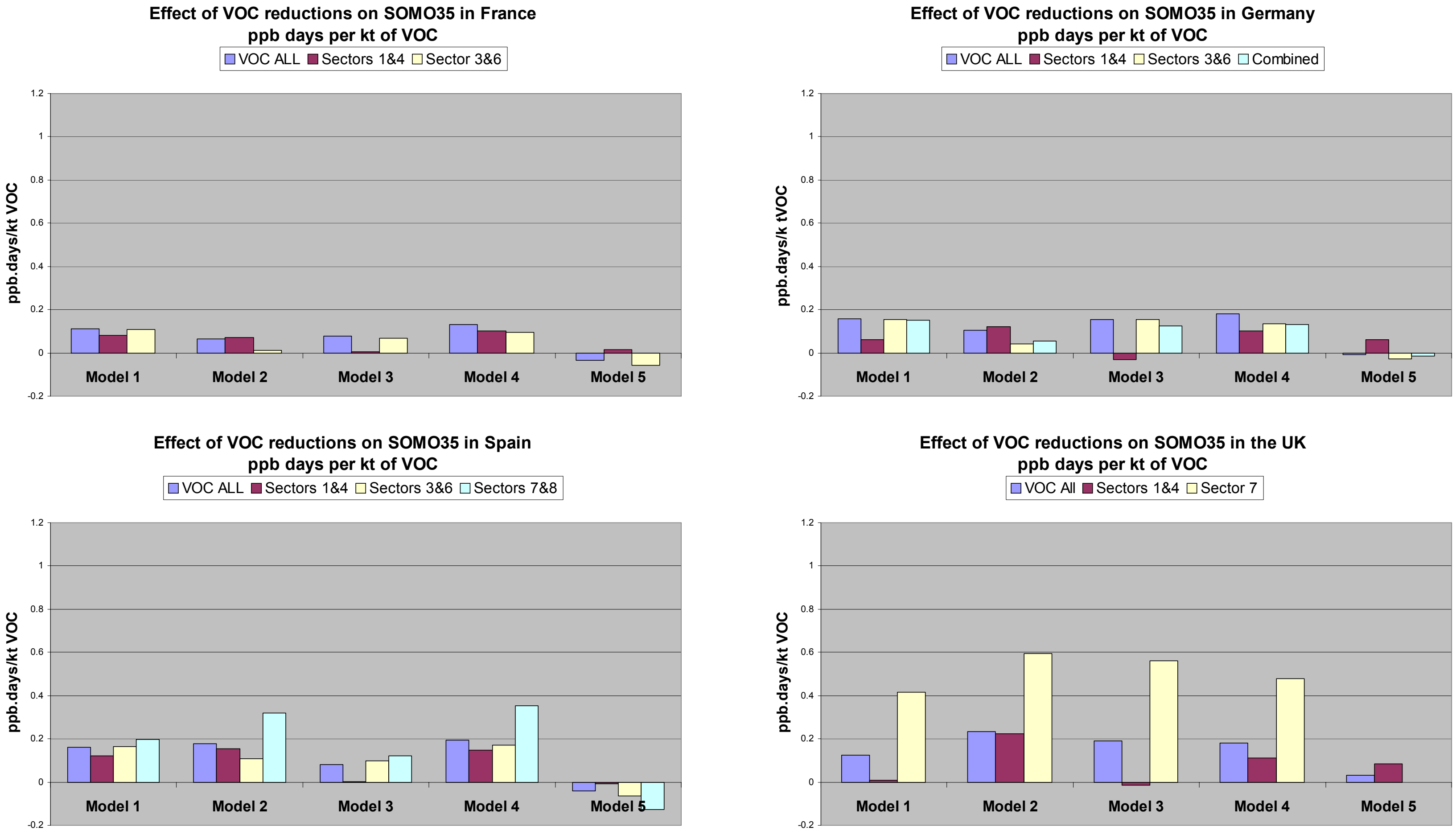


Figure 24. Effect of VOC emission reductions on SOMO35 in the countries where controls were applied.

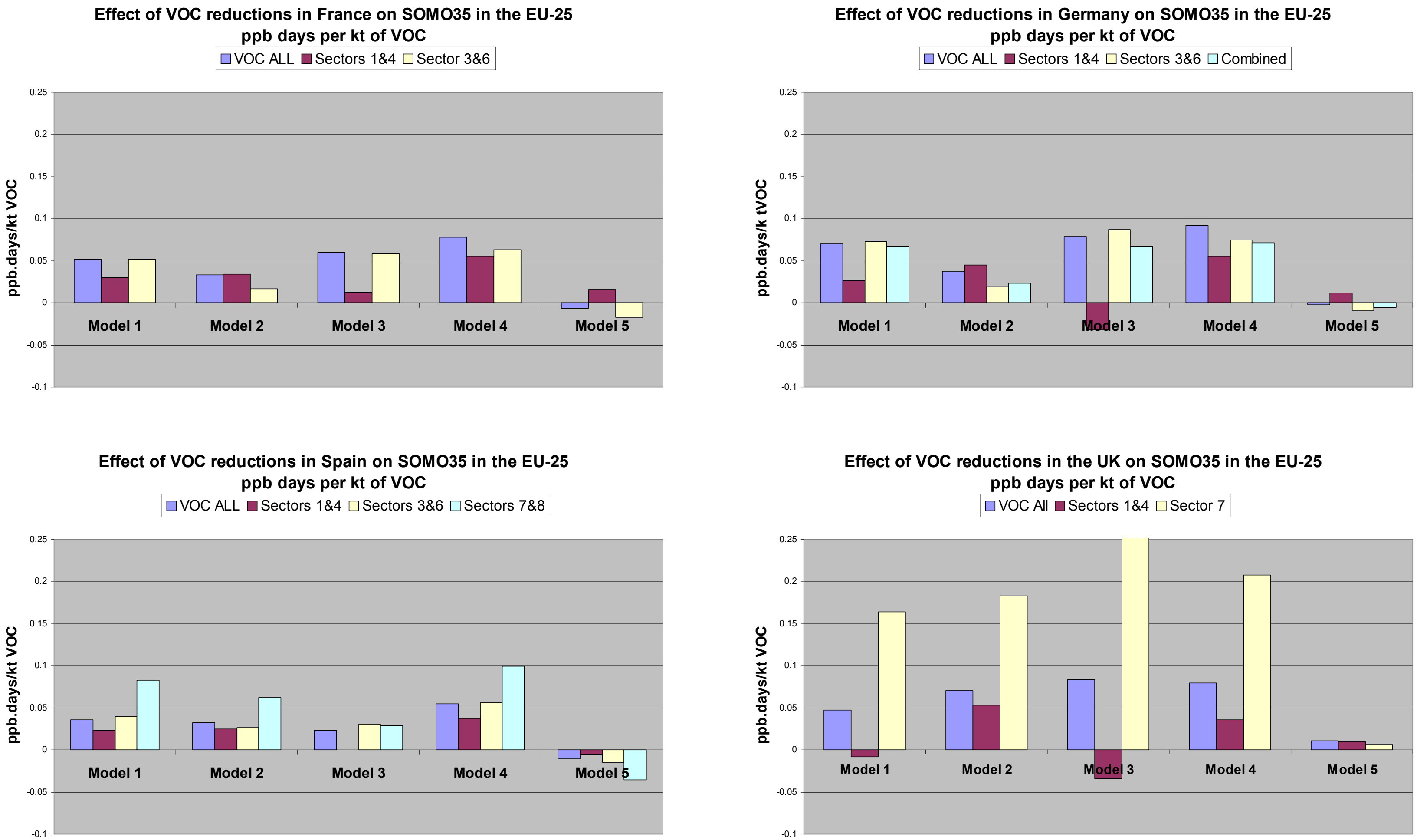


Figure 25. Effect of VOC emission reductions in each of four countries on population weighted SOMO35 in the EU-25

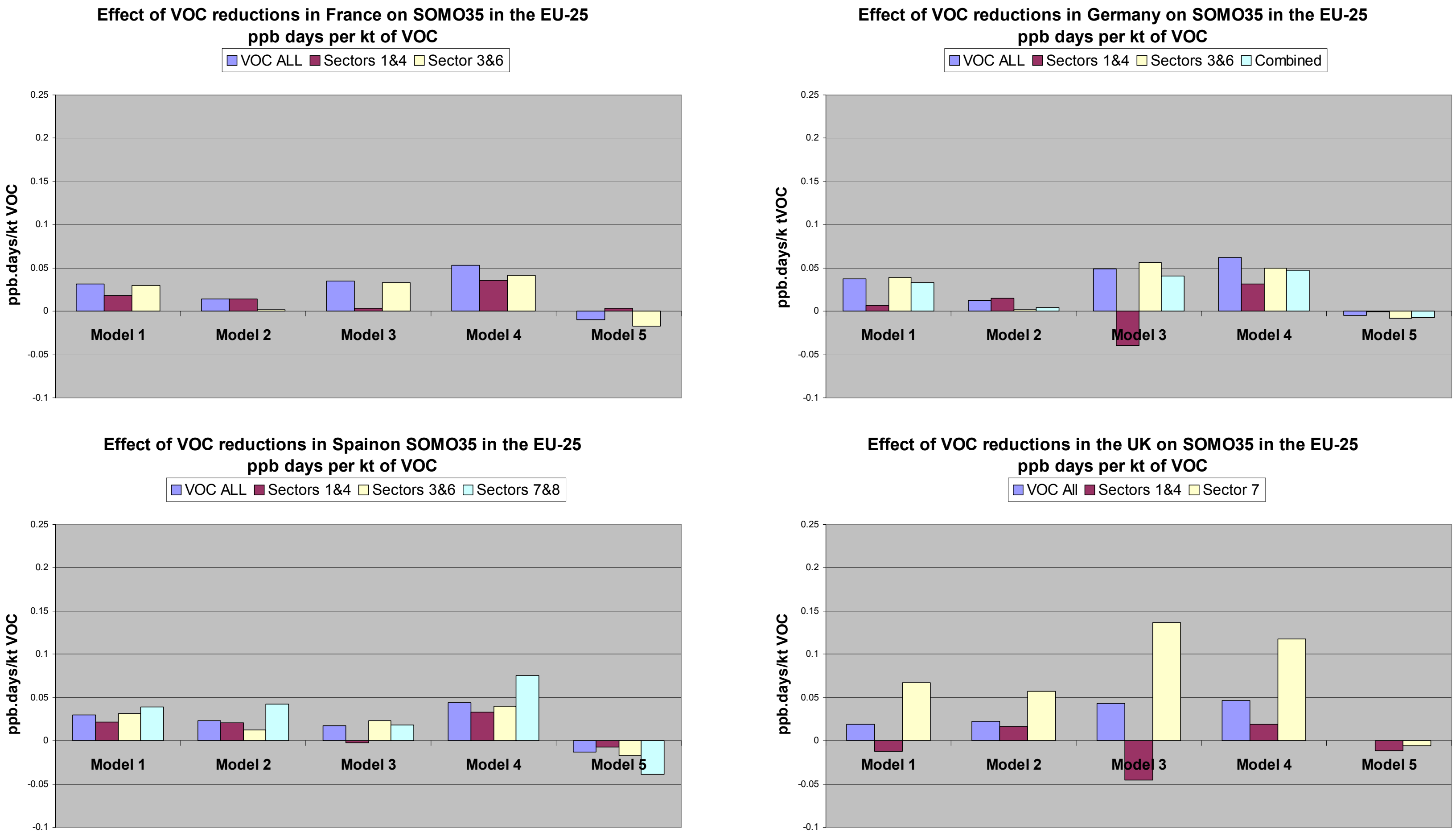


Figure 26. Effect of VOC emission reductions in each of four countries on SOMO35 in the EU-25

4.1.8 Deposition of oxidised Sulphur and Nitrogen

Figure 27 shows the amount of oxidised Sulphur deposited in the country of emission for reductions in France, Germany, Spain and the UK. The 'ALL' scenario is the leftmost bar (as will be the case for all following results). For all countries the 'ALL' scenario shows a slightly larger retention of S within the country with slightly less for the combined sectors 1 and 4. This is consistent with a greater proportion of emissions from tall stacks contributing to transboundary transport. In Spain a scenario was run for the transport sectors 7 & 8 and a greater fraction of the emission from these low sources was retained. Although there is quite a large variation between models in the predicted depositions the trends between models are consistent. The UK has overall the least proportion of emitted S retained within the country.

Figure 28. shows the retention of S by deposition to land within the whole modelling domain. The domain is different for different models. The sectoral results are more homogeneous and similar to the 'ALL' scenario.

Figure 29. shows the deposition of oxidised Nitrogen within the country of emission change. In France all the models agree that a change in Sector 1 emission is less effective than the 'ALL' scenario and that Sector 7 emission is more effective (results for Model 5 were corrupt). A combined scenario (proportionately changing 1, 3 and 7) was similar to but still different to the 'ALL' scenario indicating that other sector emissions are important. Germany, Spain and the UK showed the same trend with slightly less difference between scenarios. All models produced the lowest retention of Nitrogen within the UK.

Figure 30. shows the deposition of oxidised Nitrogen to land sources within the modelling domain. As for Sulphur the sectoral differences are smaller and the combined scenario is closer to the 'ALL' scenario. The trend for the Secrtor 1 reduction to be less effective and the sector 7 reduction to be more effective is still apparent and reproduced by all models.

Figure 31 shows for completeness the deposition efficiency of reduced Nitrogen. Because a single source (sector 10) dominates the ammonia emission this also comprises the 'ALL' scenario. All models predict that the deposition of reduced nitrogen is about twice as effective as that of oxidised nitrogen and this holds true also for the wider domain as shown in Figure 32.

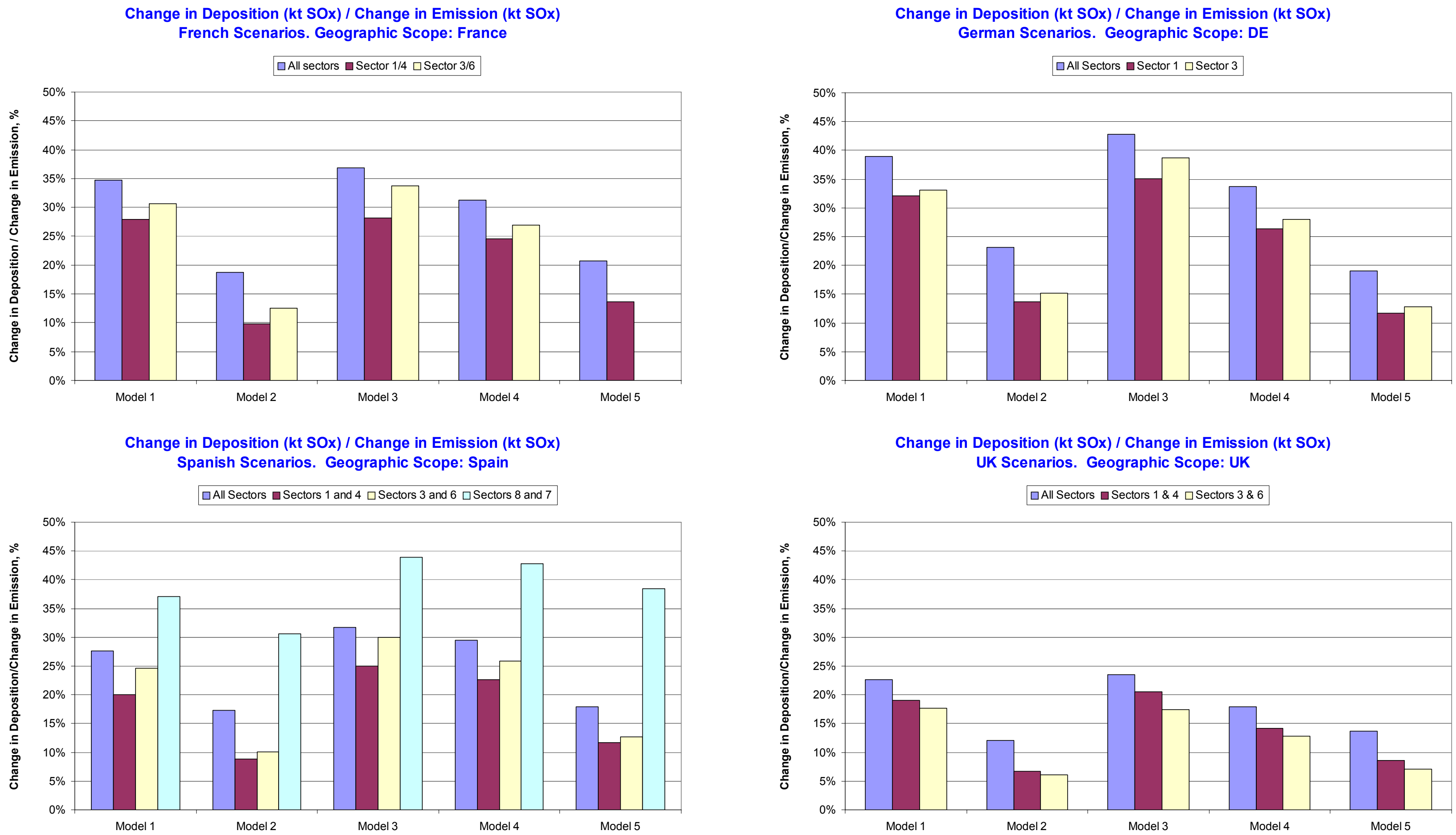


Figure 27. Deposition of oxidised sulphur in a country as a fraction of the oxidised sulphur emitted in that country, % (S/S)

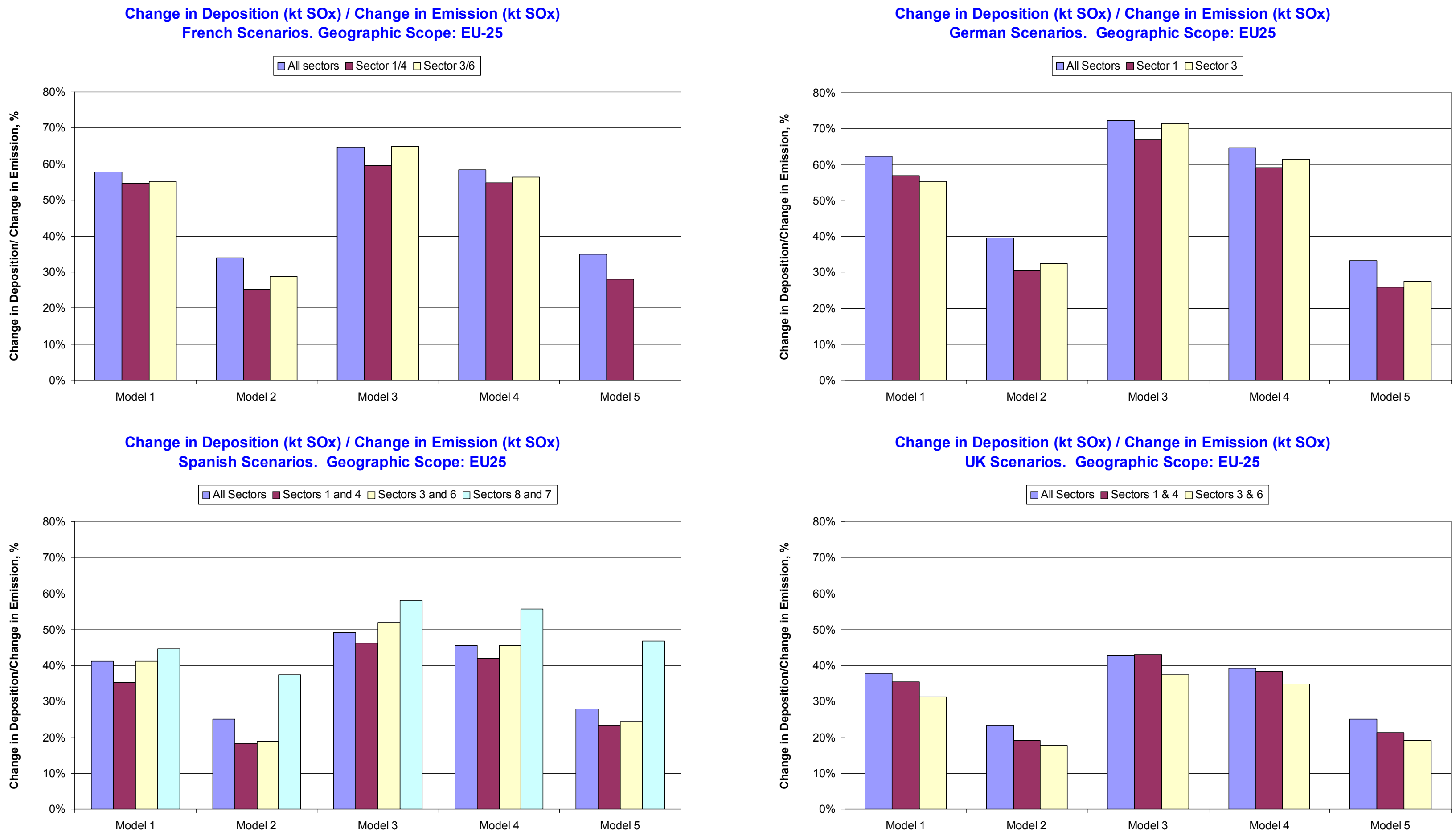


Figure 28 Deposition of oxidised sulphur in the whole domain as a fraction of the oxidised sulphur emitted from a country, % (S/S)

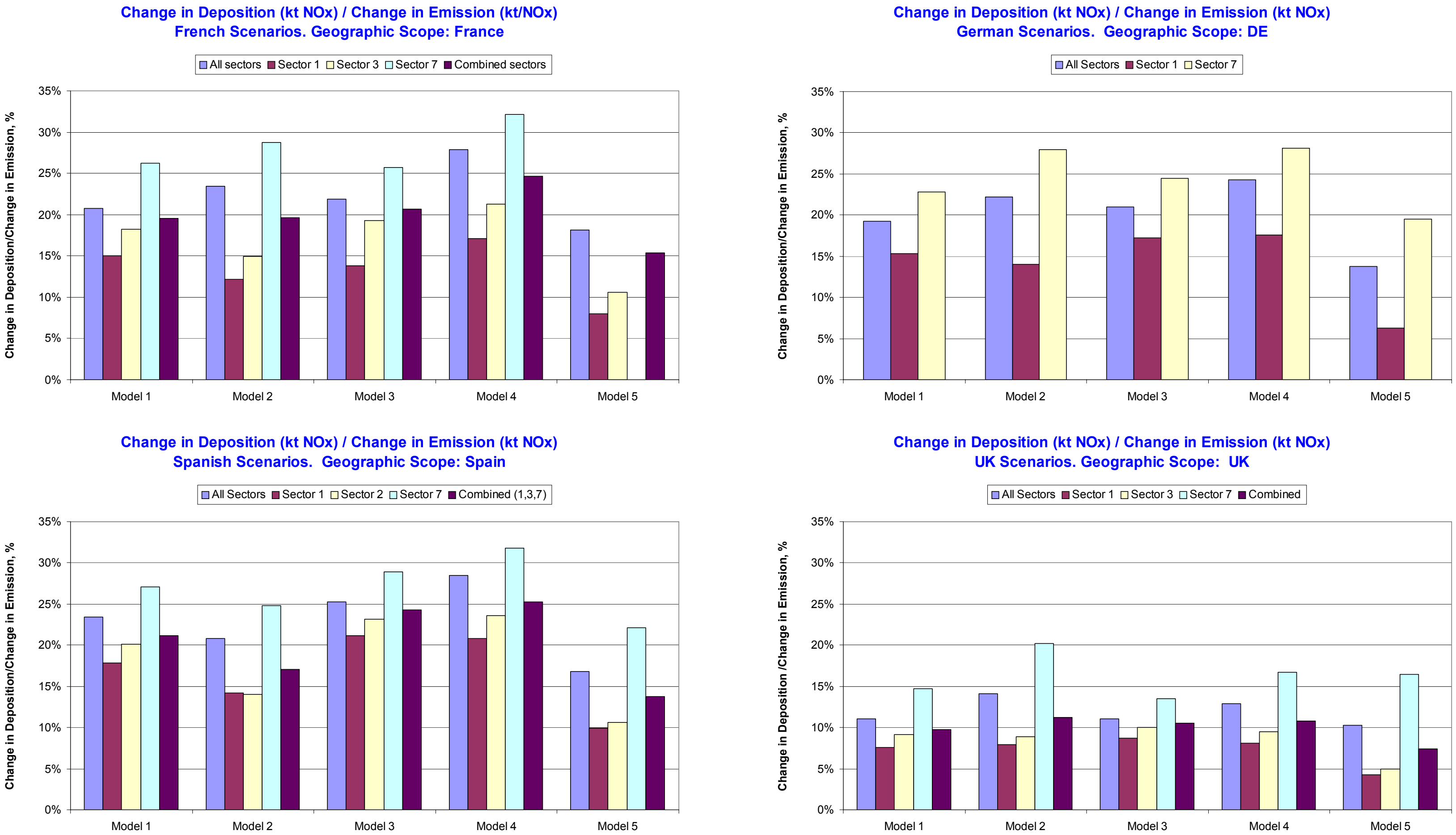


Figure 29. Deposition of oxidised nitrogen in a country as a fraction of the oxidised nitrogen emitted in that country, % (N/N)

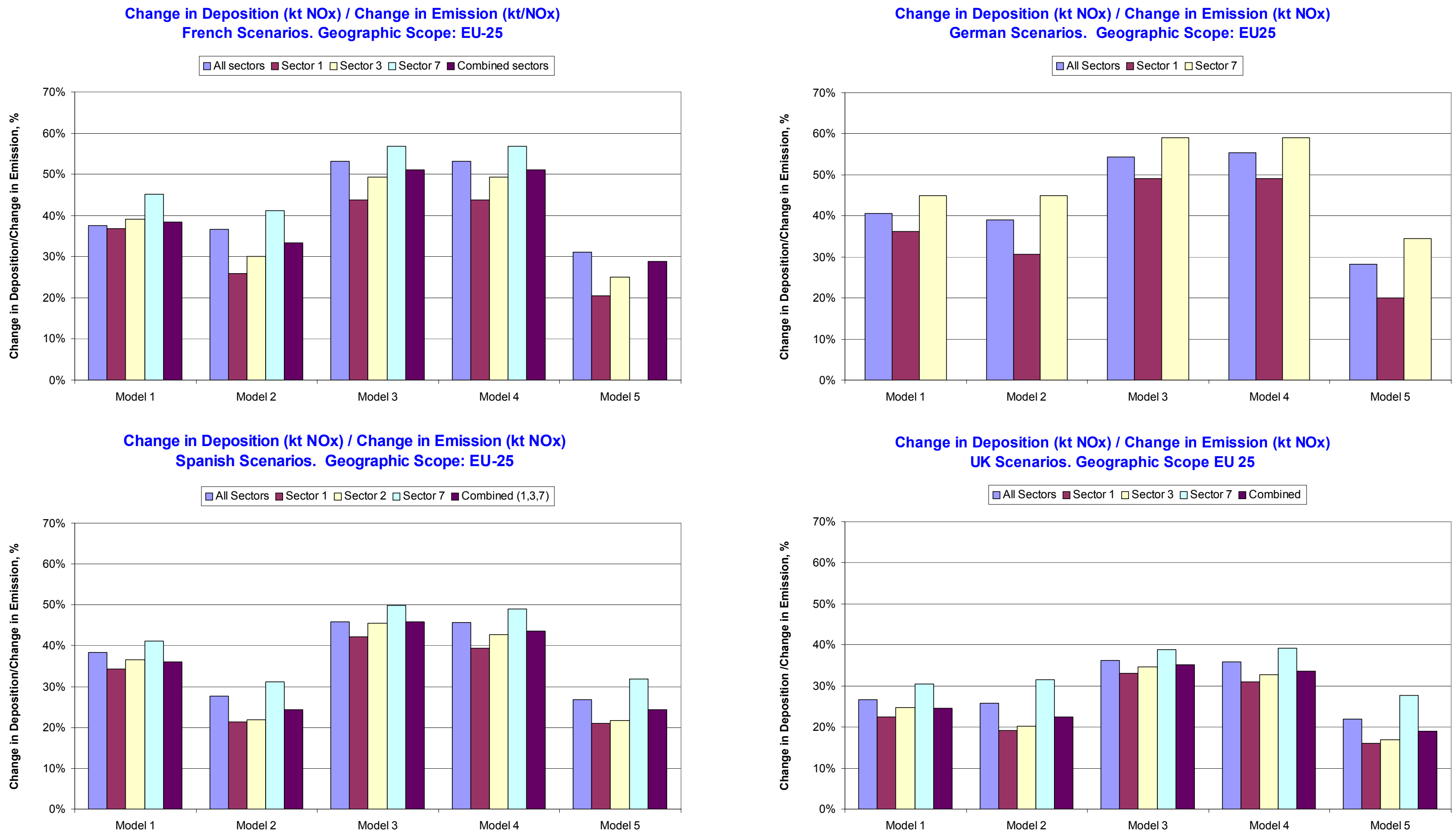


Figure 30. Deposition of oxidised nitrogen in the whole domain as a fraction of the oxidised nitrogen emitted from a country, % (N/N)

Figure 31. Deposition of reduced nitrogen in a country as a fraction of the reduced nitrogen emitted in that country, % (N/N)

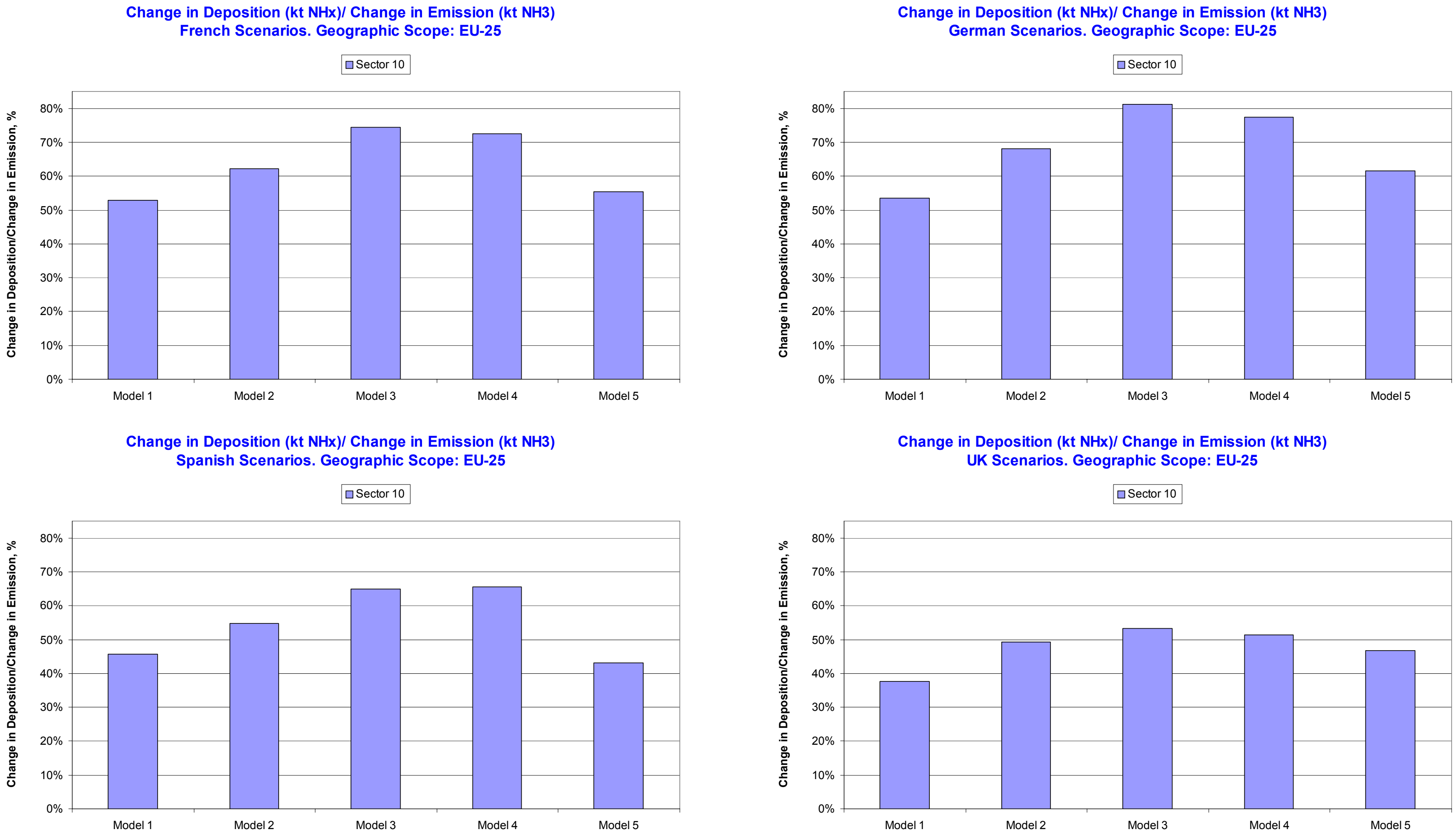


Figure 32. Deposition of reduced nitrogen in the whole domain as a fraction of the reduced nitrogen emitted from a country, % (N/N)

4.2 Scenarios for the Mediterranean Sea

It is forecast that by 2020 the role of emissions from ships will exceed land based sources in Europe. This forecast comes from an assumed compound growth in ship emissions and a year 2000 inventory developed by ENTEC for the European Commission. Concawe commissioned ENTEC to carry out a fuller inventory for the Mediterranean Sea area for the year 2005. This was to act as both a check on the assumed growth rates and to provide more detailed input data for modelling. In the event, it was found that the more detailed study produced a somewhat smaller estimate of emissions for the Mediterranean, even before accounting for growth over the five years to 2005.

In this work the CONCAWE inventory has been used for the Mediterranean scenarios. Growth to both 2010 and 2020 has been assumed at the same rate as by the EC. A value of 3.9% per year for passenger ships and 2.5% per year for all other vessels is used. A low growth scenario of only 2% has also been included for comparison purposes. The coastal region has been described in detail at a resolution of 10*10 km in order to better estimate coastal traffic passing within the 12 mile limit, however, for this study the modelling is conducted at approximately 50*50 km and so the input data has been aggregated to this scale.

Three emission scenarios have been evaluated for the reference year 2010. These are a base case whereby all ships burn fuel oil at 2.7%S and gasoil at 0.1%S, a case whereby ferries burn 1.5% S fuel and a case whereby ships at berth in port are restricted to a fuel of 0.1% S. These measures reflect actions affecting the Mediterranean sea following adoption of the EU Marine Fuel Directive that requires 1.5% S fuel to be used in the North Sea and Baltic consistent with (and preceding in implementation) the requirements of Marpol Annexe VI. Requirements of the IMO NO_x code on NO_x emissions are included.

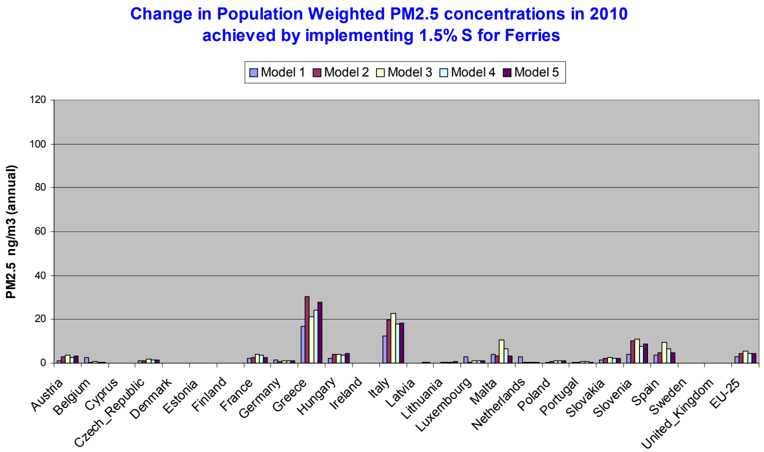
Seven emission scenarios have been evaluated for the reference year 2020. The growth rates are for overall transport volumes and emissions rise proportionally. Next a comparative case with a lower growth rate of 2% per annum. Control scenarios are:

- The entire Mediterranean as a SECA
- The 12 mile limit as a SECA
- The 12 mile limit as a SECA excepting the straits of Gibraltar
- The Aegean Sea as a SECA
- A 40% reduction in NO_x to approximate future more severe NO_x controls.

4.2.1 Effectiveness of the European Commission policy on ship emissions

The net benefit of the existing legislation on ship emissions in 2010 is shown in Figure 33. The change in $PM_{2.5}$ is shown for all the EU-25 countries excepting Cyprus. The effect of controls on ferries benefits Greece, Italy, Malta, Slovenia and Spain by a small amount. The largest benefits are for Greece and Italy but the magnitude is small at about 20 ng/m^3. The baseline concentration, shown in Figure 34 is much greater in size; about 4000 ng/m^3 for Greece and 6000 ng/m^3 for Italy, and so the benefit is tiny. The measure to implement usage of 0.1%S in ports is more effective. Model 3 response for Malta is larger than that for the other models and sets the graph scale but otherwise model results look very similar. The benefit to

Italy and Malta is about 50 ng/m^3, to Greece, Slovenia and Spain between 20 and 30 ng/m^3. The benefits of the two measures are additive.



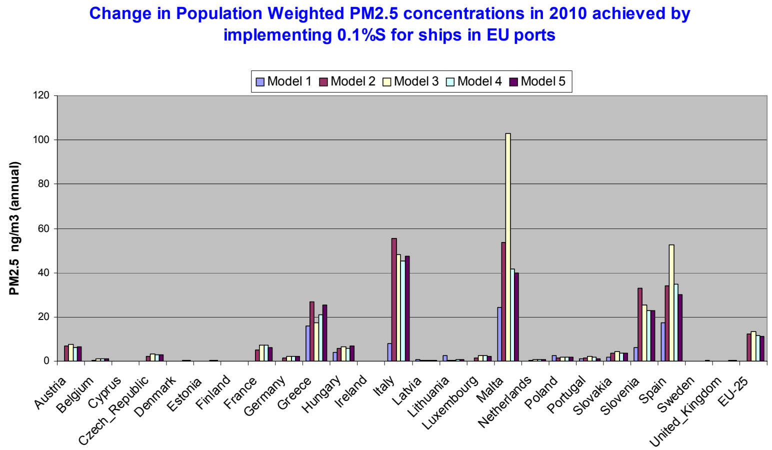


Figure 33. Effect on PM2.5 concentrations in EU countries due to the EU policy on ship emissions

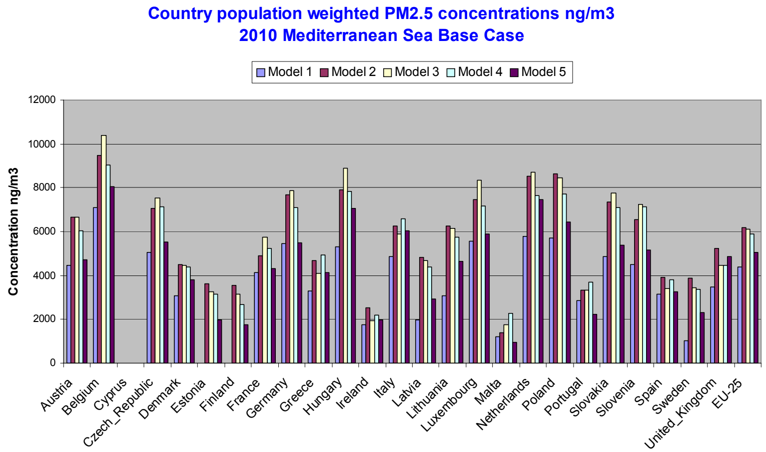


Figure 34. PM2.5 concentrations in EU countries for the Base Case 2010 scenario

4.2.2 Scenarios for 2020 in the Mediterranean

The four main fuel based emission change scenarios are shown in Figure 35. These are the growth at 2%, which is an effective emission reduction relative to the base case; the SECA scenario for the whole Mediterranean; the 12 mile zone as a SECA and the Aegean as a SECA.

We only show results for the 12 mile zone as SECA excluding the Gibraltar straits. Including the Gibraltar strait makes very little difference to the results and there was a problem with model 1 showing benefits in Northern Europe from such a measure which is unrealistic. The anomalies are not apparent in the results without Gibraltar.

It is clear that the case where only the Aegean is declared a SECA benefits only Greece and by a very small amount.

The whole Mediterranean as a SECA benefits several countries. The main ones are as before Greece, Italy, Malta, Slovenia and Spain. As before model 3 gives a much higher signal for Malta than the other models and sets the display scale of the graphs. The basic order of magnitude of the benefit is 100 – 150 ng/m^3. This is again a small improvement over the base case concentrations, Figure 36, 4000 – 5000 ng/m^3 for the larger countries and 1000 – 2000 for ng/m^3 for Malta.

The 12 mile zone SECA produces a similar benefit to the 2% growth scenario relative to the base case. Beneficiary countries are Greece, Italy, Malta, Slovenia and Spain with a $PM_{2.5}$ reduction of approximately 50 ng/m^3. For Italy the benefit is slightly larger for the 2% growth scenario.

The effect of NO_x concentration changes is shown in Figure 37. This is a sensitivity scenario rather than any specific ambition for NO_x so to some extent the absolute change in $PM_{2.5}$ concentration is meaningless until we express it as a potency by scaling with the emission change. However the results are that Italy benefits the most with a $PM_{2.5}$ reduction of between 100 and 200 ng/m^3 depending on model. Slovenia and Spain are next highest with benefits of between 50 and 100 ng/m^3. The models disagree about Malta with 2 giving a low benefit of about 25 ng/m^3 and two giving higher benefits of 50 and 100 ng/m^3 respectively.

As a potency the order of the benefits is unchanged. The Italy benefit is between 0.13 and 0.26 ng/m^3/kt NO_x as shown in Figure 38.

The response of SOMO35 can also be calculated as a potency as shown in Figure 39. The response is almost linear for the larger countries but, for Malta the smaller change in NO_x produces a greater response. Again the beneficiaries are Greece, Italy, Malta and to a lesser extent Slovenia and Spain. There is a lot of variation between models (factor 2) in each case. The benefits for the most affected countries are of order 0.25 +/- 0.1 ppb.days /kt NO_x.

Continuing this trend we should examine the potency of the sulphur reduction scenarios. Results, corresponding to the absolute concentration changes of Figure 35 are shown in Figure 40. We note however that there is also an implied change in primary particulate emission and the potency of this is shown in Figure 41. For the Mediterranean as a whole the potency for SO_2 reductions is of order 0.2 ng/m^3/kt in the most benefitted countries. For the 12 mile SECA the potency is about double, representing the importance of proximity. For $PPM_{2.5}$ the potency is ten times higher.

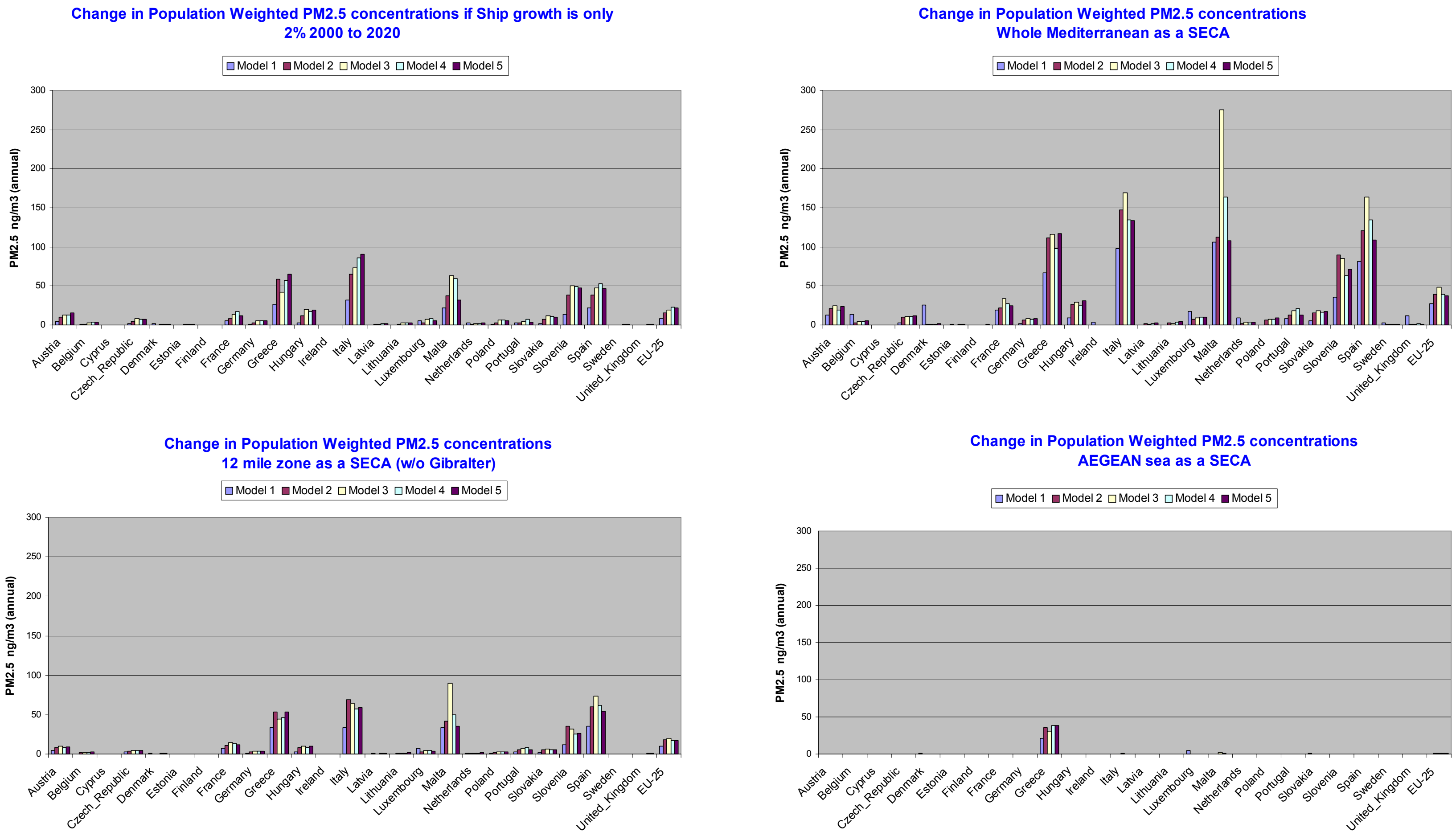


Figure 35. Effect of fuel based emission changes in Mediterranean for 2020

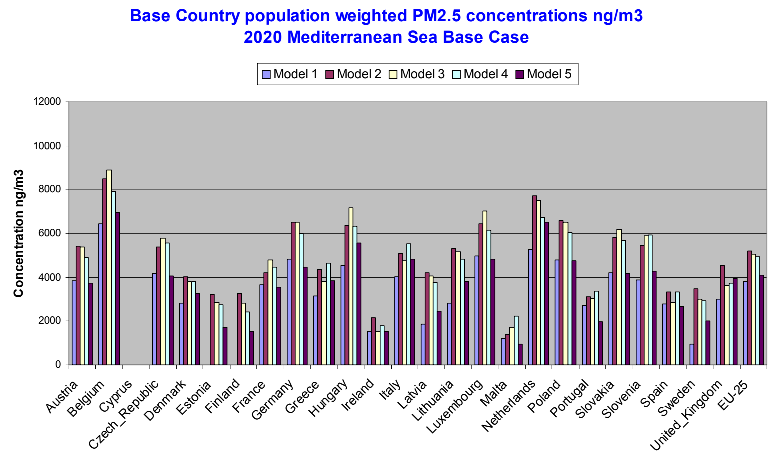


Figure 36. Base case PM2.5 concentrations for the Mediterranean Sea

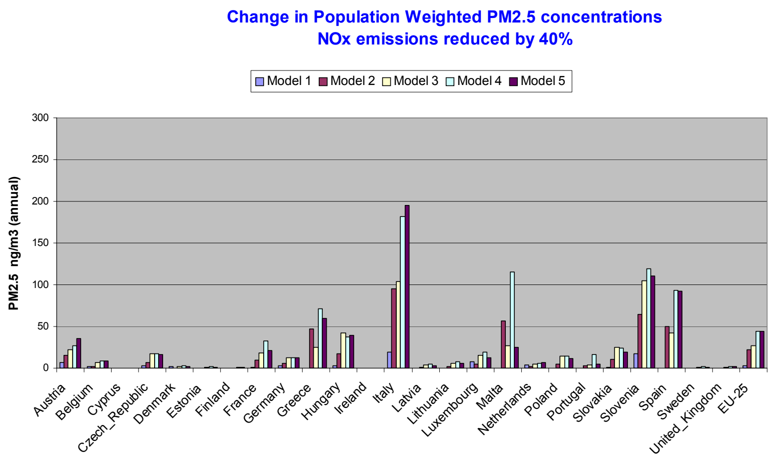


Figure 37. Effect of NOx emission change on PM2.5 concentrations

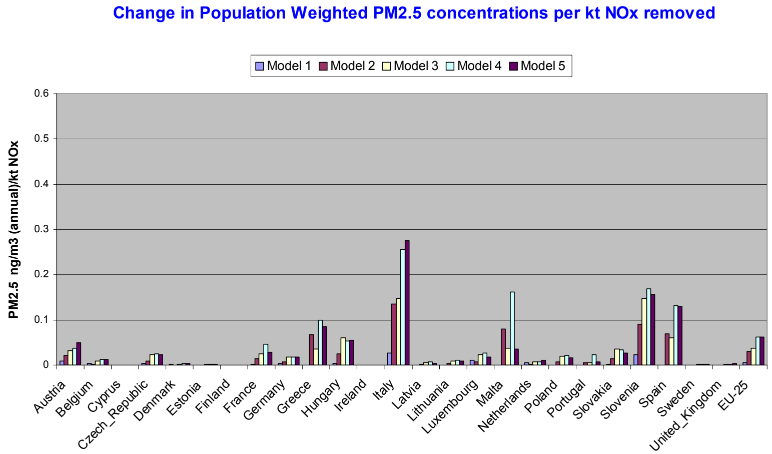
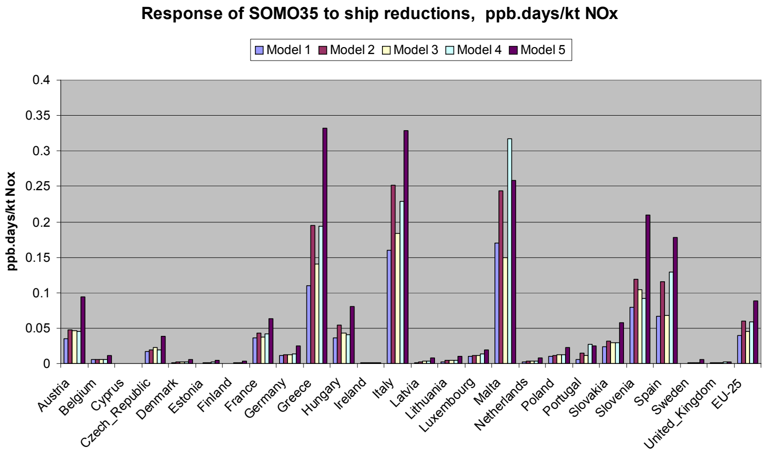


Figure 38. Data of Figure 17 normalized with the size of NOx emission.



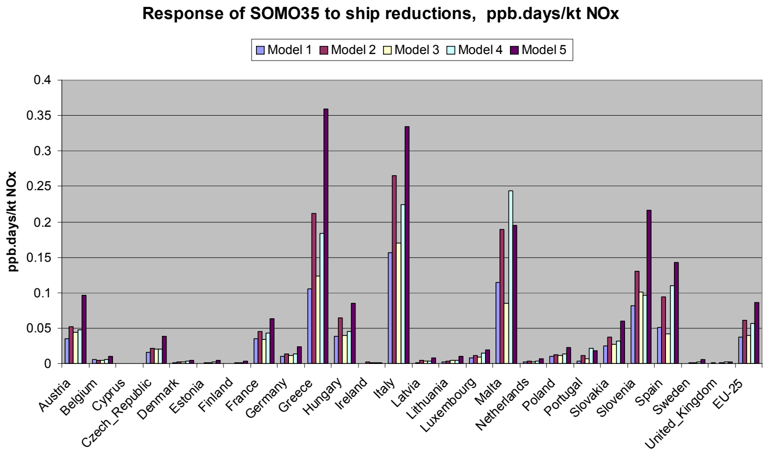
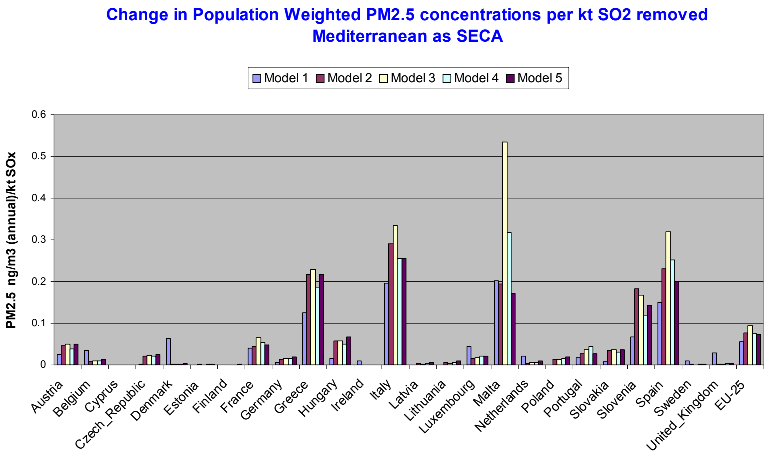


Figure 39. Change in SOMO35 with NOx emission in the Med Sea, left the 40% reduction scenario, right the 2% growth scenario relative to base case



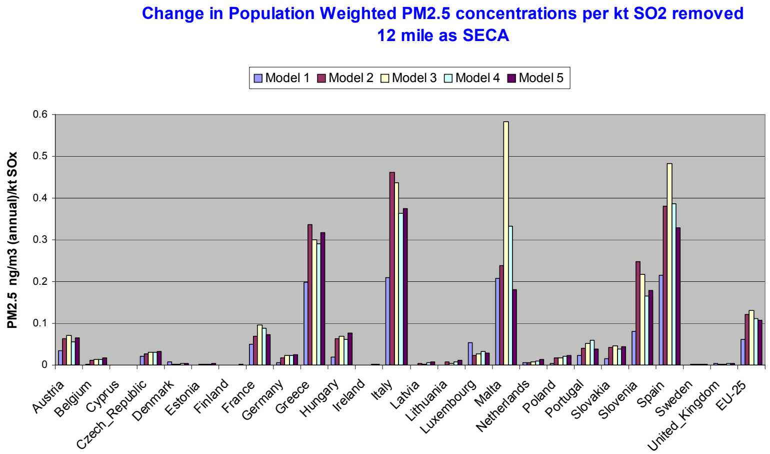
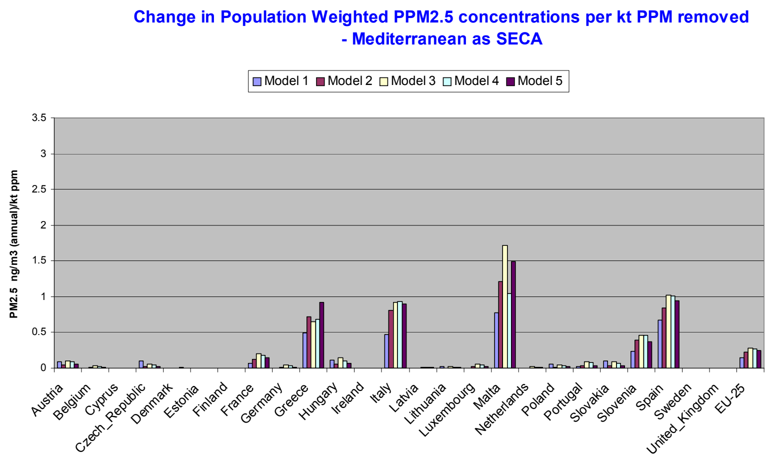


Figure 40. Potency of SO_2 emission reductions in the Mediterranean Sea



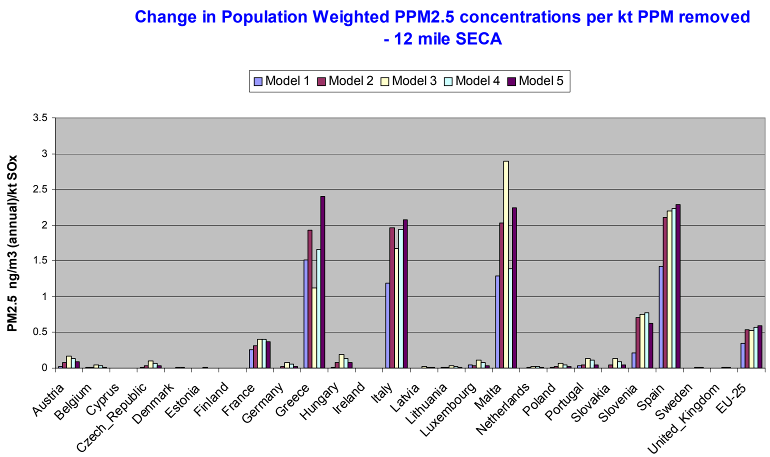


Figure 41. Potency of $PPM_{2.5}$ reductions in the Mediterranean Sea

4.3 Comparison of land and sea based measures

It is appropriate to compare the potency of land and sea based measures in the light of the current discussion that assigns a great importance to the affect of sea based emissions on on-land air quality.

Figure 42 shows the relative effectiveness of Sulphur and NO_x controls in the Mediterranean on $PM_{2.5}$ compared with the land based sources. Here the Mediterranean Sea controls are the least effective according to all of the models. The potency is between 2 and 3 times less than Spain for both SO_2 and NO_x controls. This is perhaps surprising considering that the proximity of the Mediterranean to the EU countries would be considered more than that of Spain. Of all the comparisons Germany is the country where controls have the greatest potency. The potency of controls in the Mediterranean is up to 10 times less than Germany. There is a factor 2 variation between models.

Figure 43 shows the incremental potency of extending the SECA zone from 12 miles to the whole of the Mediterranean. The 12 mile zone SECA results are calculated as before, using the impact on the whole EU as the benefit measure. The 12 mile impacts are then subtracted from the whole Mediterranean SECA benefits and normalised with the emission reduction raking place outside of the 12 mile zone. The results show that the models agree that for primary PM the potency is greatest for the 12 mile zone and that the emissions outside of that zone contribute much less to on-land $PM_{2.5.}$ For SO_2 the emissions outside of the 12 mile zone have a potency between 1/2 and 1/3 that of the 12 mile zone.

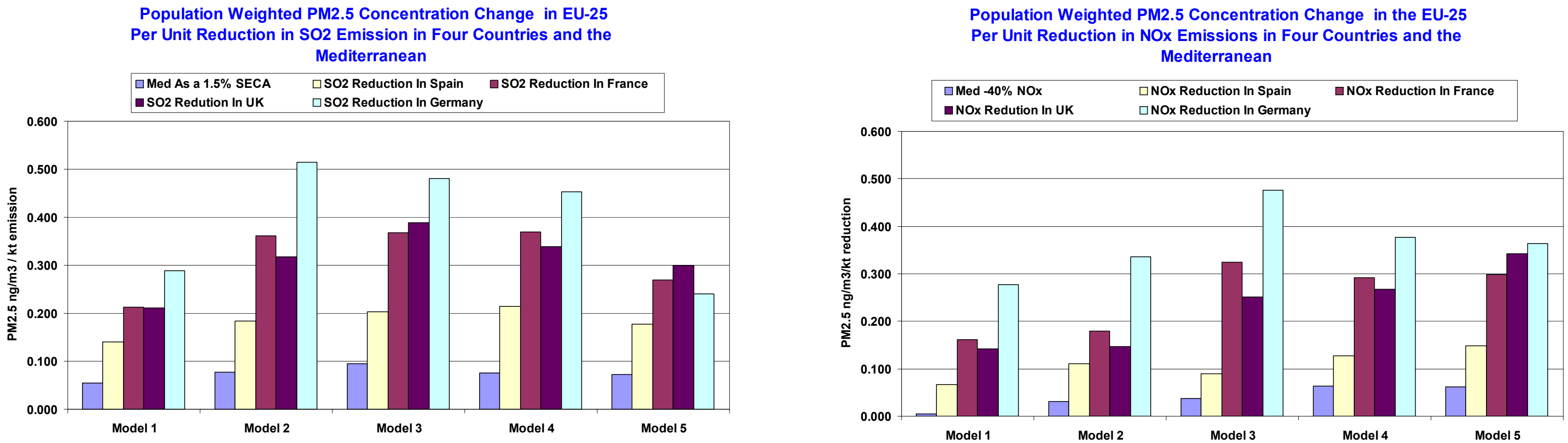


Figure 42. Comparative Effectiveness of Emission reductions in Four Countries and the Mediterranean Sea on PM2.5 concentrations in the EU-25.

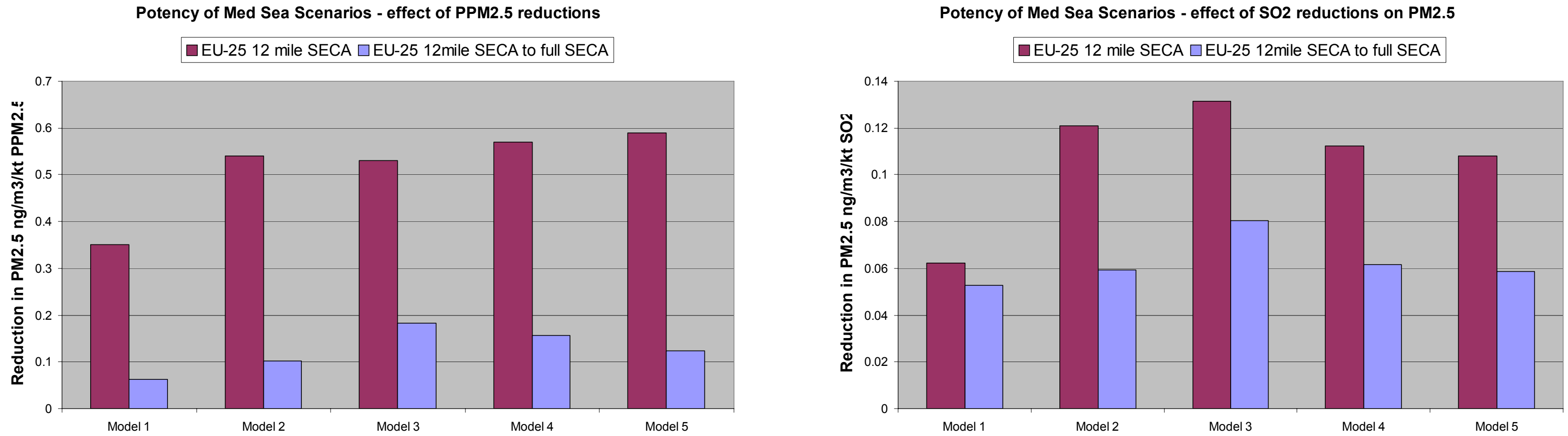


Figure 43. Potency of emission reductions in 12 mile zone compared with the remaining Mediterranean Sea, left primary PM2.5 and right SO_2. Note different scales.

5. Conclusions and recommendations

The Joint Research Centre of the European Commission working with five internationally recognised air quality modelling teams at Ineris (France), the Free University of Berlin (Germany), Met.no (Norway), TNO (Netherlands) and SMHI (Sweden) has developed the EuroDelta II project toolkit. The modelling teams have explored 60 emission scenarios to explore how environmental impacts (depositions and concentrations) depend on land-based sectoral and on ship emission changes.

This report has summarised some of the results that can be derived from the toolkit. We have examined deposition, both of oxidised sulphur and of both oxidised and reduced nitrogen; the concentration of fine particulate matter and SOMO35; an ozone measure relevant to human health effects. Aggregate measures have been used to express the effect of an emission change on conditions within the country of change and within the whole modelling domain.

The domain approximates the EU-25 and includes most countries of the European Union, the principle omissions are the Baltic countries, Finland, Sweden, Denmark and Cyprus. The United Kingdom (except Northern Scotland), France, Germany and Spain, in which the sectoral emission reductions are tested, are well within the domain. These four countries account for 53% of the total EU population. The Mediterranean Sea extent east of the Aegean and south of Turkey is not included in the overlap area. Four of the models have larger domains and cover almost all of Europe.

Much more detailed analysis can be carried out and it is planned to make the toolkit available for such studies.

The EuroDelta II project was motivated by interest in whether emission reductions in different industrial sectors would necessarily have the same effectiveness in reducing environmental impacts across Europe. Here effectiveness is measured by the change in impact per change in emission.

The source receptor relationships used to determine how country wide emissions contribute to impacts in individual EMEP grid squares are derived by perturbing national emissions, and in so doing, assigning emission reductions proportionately across all sectors.

On the other hand, when designing policy on a cost-effectiveness basis which is at the heart of integrated assessment methods, controls on those sectors where sufficient emission reductions can be achieved at least cost are likely to be preferred.

If there is a mismatch in the assessed effectiveness of sectoral emission reductions, particularly if a sectoral reduction is less effective than thought, this could lead to either underachievement in the ambition to meet an environmental improvement target or an underestimate of the cost of achieving it. Either of these would have serious consequences for a country making choices as to how to achieve its national emission ceiling.

Models used in this study will return different absolute numerical results for each of the scenarios. This was investigated as part of the EuroDelta I project and we are not primarily concerned here as to why one model predicts a different number to another. We are interested in consistency of trend in the model predictions, such that if all models predict a similar efficiency difference between sectors then we can be more confident in the result.

In the findings below the "ALL" scenario refers to the case where emissions are reduced proportionately across all sectors.

Regarding particulate matter:

- All the models agree that there are differences in effectiveness of emission reductions between sectors. This is broadly consistent with a physical interpretation that the more effective reductions are for sectors where proximity of emission to people is greatest. Thus, higher effectiveness is seen from sectors emitting at low level and distributed according to population and lower effectiveness is seen for sectors emitting from large point sources as these are fewer in number, emissions are released from great height (taking plume rise into account) and generally the association with populated areas is less.
- The differences between sectors is greater for population weighted compared with non-weighted concentrations.
- The above is true whether the impact is assessed EU wide or in the country in which the emission control takes place.
- All models show that the 'ALL' scenario gives a significantly different effectiveness to the sectoral effectiveness and this applies to all the pollutants contributing to $PM_{2.5}$ concentrations (NO_x, SO_x, $PPM_{2.5}$).
- The sectoral response is not the same in all countries and is different for each pollutant and in particular the potency of ammonia emissions as they affect $PM_{2.5}$ is much larger (by a factor of two) in the UK than for other countries.

The sectoral efficiencies for the different sectors are given in Table 2 to Table 7.

Regarding ozone (as measured by SOMO35)

- There are considerable country differences in the response of SOMO35 to NOx reductions. The effectiveness does not depend on whether area or population weighted results are used. In France sector 1 controls have less effect than other sectors which are similar to the 'ALL' scenario. In Germany and Spain there is much less variation between sectors. In the UK SOMO35 is predicted to increase rather than decrease with NO_x reductions albeit by a very small amount.

There are some doubts about the robustness of the studied SOMO35 response to VOC controls. To limit the number of calculations needed we assumed that changes in SO_2 emissions would have no effect on ozone when partnered with VOC emission changes. This is not necessarily the case. Unfortunately we did not carry out any cases where SO_2 and VOC were varied independently and which could have been used to quantify any effect. Therefore the following observation from the study may not be robust. It is included for completeness and, because interested parties using the toolkit would find the same result, to ensure this caveat is recorded.

- There are considerable differences in the response of SOMO35 to VOC reductions across countries. In France and Germany the effectiveness is small. In Spain and the United Kingdom emission reductions in the transport sectors are much more effective than the all scenario and the results are dependent on whether population or area weighted values are used, being greater for the population weighted results.

Regarding deposition we find::

- Differences in sectoral efficiency were more varied for oxidised Nitrogen deposition than for oxidised Sulphur deposition. Deposition of nitrogen in the country of emission change was generally less than that of Sulphur indicating greater transboundary transport of Nitrates.
- For Sulphur, all models predicted that emission reductions in sector 1 were less effective than the ALL scenario for sulphur. Only a single case for Spain which looked at emissions from sectors 7 and 8 combined had a greater efficiency. The amount of Sulphur retained on land in the whole domain was generally less than twice that retained in the country of emission. Sectoral differences were less marked when looking at the whole domain than when looking at individual country results.
- For Nitrogen, all models predicted a lower efficiency for emission reductions in Sector 1 compared with the 'ALL' scenario for deposition within the country of control. Emissions reductions in sector 7 were generally more effective than the 'ALL' scenario. Again, if retention in the entire domain was considered then sectoral differences became smaller. The amount of Nitrogen retained on land in the whole domain was about twice that retained in the country of emission. Only about half of all Nitrogen emission reduction is accounted for by deposition to land within the domain.
- Reduced nitrogen deposition is dominated by the agriculture sector and so relative efficiencies do not apply. Dispersion is of much shorter range than for oxidised nitrogen with much more retained in the domain.
- A useful extension of this work would be to include information on detailed ecosystem impacts (critical loads, forest, crop and ecosystem locations) as weighting factors for the deposition calculations.

Regarding Mediterranean Sea Emissions:

- Emission changes benefit a limited number of countries: Greece, Italy, Malta, Slovenia and Spain.
- The current legislation (use of 1.5% S in Ferries) reduces 2010 concentrations in these countries by a maximum of 0.5%.
- The current legislation (use of 0.1% S in ports) reduces 2010 concentrations in the mainland countries by a maximum of 0.8% in Italy. Malta benefits more proportionally, ~ 5%, by virtue of its location and size.
- In a 2020 world, emission changes brought about if the Mediterranean were declared a SECA would produce a benefit of up to ~ 3.75% in $PM_{2.5}$ concentrations for Greece, Italy, Slovenia and Spain. Malta would benefit more proportionally because land based emissions contribute less to PM concentrations (which are lower than in other countries)
- In a 2020 world half of the benefit for $PM_{2.5}$ concentrations can be gained by declaring the 12 mile zone a SECA.
- Almost identical results are obtained if the emissions growth up to the year 2020 were only 2% per annum compared with the base case assumption of 2.5%. That is a low growth scenario gives the same difference in $Pm_{2.5}$ concentrations from the base case as declaring the 12 mile zone a SECA.

- The effectiveness of emission reductions in the Mediterranean is different according to whether emission reductions take place in the 12 mile zone or across the whole sea. Emission reductions within the 12 mile zone are about twice as effective (reduction in PM per kt of emission) than applying controls over the whole Mediterranean area.
- The $PM_{2.5}$ effectiveness of ship controls over the whole Mediterranean is largest (of the main-land countries) for Italy and amounts to ~0.2 $ng/m^3/kt$ for reductions of SO_2 or of NO_x.
- The potency of NO_x reductions on SOMO35 for the most affected countries is of order 0.25 ppb.days/kt NO_x.

Regarding the relative potency of land and sea emissions as they affect $PM_{2.5}$

- With respect to $PM_{2.5}$ concentrations across the modelled domain the effectiveness of reducing SO_2 or NO_x emissions from ships is a factor 6 (SO_2) and 10 (NO_x) smaller than the effectiveness of on-land emission reductions made in Germany, and a factor 4(SO_2) - 6 (NO_x) less than the emission changes in France or the UK.

This study has shown that there are important differences between sectors in the amount of concentration(deposition) reduction obtained by changing a pollutant emission. This difference is not accounted for in the present process used to evaluate future national emissions ceiling reductions for both beneficial effect and cost-effectiveness. This raises the possibility that, when national bodies consider how to implement an emission ceiling taking account of the information used in deriving that ceiling, choices might be made that are less effective than expected.

It is recommended that, at minimum, validation calculations are carried out as part of the NEC process to examine if the implied sectoral reductions are able to deliver the intended benefits. If sectoral weights could be incorporated into the integrated assessment itself then this may lead to an overall better recommendation for emission ceilings

Appendix A. Model Description

	RCG	MATCH	EUROS-LOTOS	EMEP	CHIMERE
Reference	Free University of Berlin Stern et all, 2006 Beekmann et al.,2007 Stern et al. 2007	Swedish Meteorological and Hydrological Institute Gidhagen et al., 2005 Andersson et al., 2007 Langner et al., 2005 Langner et al., 1998a.	TNO Schaap et al., 2005, 2008	Norwegian Meteorological Institute Simpson et al., 2003 Fagerli et al., 2004	INERIS Schmidt et al. 2001, Vautard et al. 2001, Vautard et al. 2003, Bessagnet et al. 2004
Model Configuration	- grid resol: 0.5x0.25 deg - Grid config: 80x123x 5 - 1st vertical level: 20 m - vertical extent: 3000 m	- grid resol: 0.4x0.4 deg - Grid config: 84x106x14 - 1st vertical level: 60m - vertical extent: ca 5500 m	- grid resol:: 0.50x0.25 deg - Grid config: 100x140x4 - 1st vertical level: 25 m - vertical extent: 3500 m (V1.2)	- grid resol: ca 50 x 50 km - Grid config: 132x111x20 - 1st vertical level: 90m - vertical extent: 100 hPa = ~ca 16180m	- grid resol: 0.5x0.5 deg - Grid config: 70x44x8 - 1st vertical level: ca 20 m - vertical extent: 500 hPa
Meteorology	Diagnostic meteorological analysis system based on optimum interpolation on isentropic surfaces (TRAMPER).	numerical weather prediction (NWP) model HIRLAM	Diagnostic meteorological analysis system based on optimum interpolation on isentropic surfaces (TRAMPER).	3-hourly resolution meteorological data from PARLAM-PS, This is a dedicated version of the HIRLAM numerical weather prediction (NWP) model, with parallel architecture and same resolution as the CTM EMEP model	1°x1°(ECMWF) data refined by MM5 simulations (36 km in resolution)

	RCG	MATCH	EUROS-LOTOS	EMEP	CHIMERE
Boundary Conditions	Based on observations at background locations, for O3 based on Logan's O3 climatology	Partly based on observations at background locations and partly on large-scale model calculations	For O3, based on Logan database. For PM and its components based on observations	For O3, 3D-fields are specified from observations from Logan and then adjusted to ensure consistency. For other components , interpolation based on observations.	*For gas phase*, monthly average values of the LMDzINCA climatological simulations. *For particulate*, monthly averaged GOCART model simulation for dusts, organic and black carbon, and sulfate.
	Addition of 3 ppb for 2020 background ozone				
Emissions					
VOC Split	Mass-based, source group dependent NMVOC profiles	Mass-based, source group dependent NMVOC profiles	Mass-based, source group dependent NMVOC profiles	Mass-reactivity weighting of real emission following Middleton et al. (1990)	- AEAT speciation (AEAT, 2002. - Mass-reactivity weighting of real emission following Middleton et al. (1990)
PM Split	For PM2.5 and coarse PM; PM2.5 divided into mineral dust, EC and primary OC. For the OC and EC fractions in PM2.5 see Stern et al. 2008.	PPM emissions split into three size bins (Aitken, accumulation and coarse mode).	PPM2.5 and PPM10-2.5 Of all SOx emissions 2% is assumed to be sulphate	Only primary split into two modes (PM2.5 and PM10)	Only primary split into two modes (PM2.5 and PM10)

	RCG	MATCH	EUROS-LOTOS	EMEP	CHIMERE
Biogenic	- E94 emission factors for isoprene and OVOC - Other VOCs as in Simpson et al. (1995). - Terpene emission factors taken from CORINAIR - Light intensity and temperature dependencies considered.	- E94 emissions factors for isoprene - Oceanic sulphur treated as SO2. - Volcanic sulphur split into 89% SO2, 2.2% sulphate and rest unreactive	- isoprene emissions are calculated following Veldt (1991)	- Isoprene and alpha-pinene computed according to Simpson et al. (1995), - Volcanic Sulfur as SO2. - DMS from oceans from Tarrason et al., 1995	- computed according to Simpson et al. (1995), for alpha-pinene, NO and isoprene - Volcanic Sulfur: 99% SO2, 1% sulfate
Soil NO	- function of fertilizer input and temperature (Simpson et al., 1995).	None	None	Not included	- function of fertilizer input and temperature (Simpson et al., 1995).
Other	No NO_x from lightning			NOx emissions from lightning from Köhler et al., 1995	No NO_x from lightning HONO emission set to 13% of NO2
Temporal factors	As specified from Eurodelta Web page				
Height releases					

	RCG	MATCH	EUROS-LOTOS	EMEP	CHIMERE
Gas Chemistry Scheme	- updated CBM-4 - Carter's 1-Product Isoprene scheme - Homogeneous and heterogeneous conversion of NO2 to HNO3 - Aqueous phase conversion of SO2 to H2SO4, through oxidation by H2O2 and O3. - Equilibrium concentrations for SO2, H2O2 and ozone from Henry constants and assuming progressive cloud cover for relative humidity above 80%. - Effective rate constants for aqueous phase reactions SO2+H2O2 and SO2+O3 calculated for an average pH of 5 using acid / base equilibrium and kinetic data from Seinfeld and Pandis (1998).	- Simpson et al. (1993) - Carter's 1-Product Isoprene scheme. - Aqueous phase conversion of SO2 to H2SO4, through oxidation by H2O2 and O3. - Equilibrium concentrations for SO2, H2O2 and ozone from Henry constants using NWP cloud cover and cloud water content. - Effective rate constants for aqueous phase reactions SO2+H2O2 and SO2+O3 calculated for an average pH of 5.	TNO CBM-IV scheme (Schaap et al., 2005) Heterogeneous formation of sulphate represented by an effective first order rate constant depending on RH and cloud cover. (Schaap et al., 2004a) N2O5 oxidation on aerosols explicitly calculated (Schaap et al., 2004a)	EMEP/MSC-W scheme (Andresson-Sköld and Simpson, 1997, 1999)	MELCHIOR-2 - (lattuati, 1997, based on the EMEP mechanism) - Heterogeneous reactions for HNO3 formation. - Aqueous phase conversion of SO2 to H2SO4 through oxidation by H2O2 and O3 (pH in the range [5 – 6]. - Isoprene and terpene chemistry.
Numerics	QSSA solver with variable time step	Rosenbrock solver, "RODAS-3" (Sandu et al., 1997)	TWOSTEP	TWOSTEP solver	TWOSTEP solver

	RCG	MATCH	EUROS-LOTOS	EMEP	CHIMERE
Species & reactions	42 species., 96 reactions	130 reactions and 61 chemical components.	28 species and 66 reactions	71 species and 130 reactions	44 gas-phase species
Aerosol Chemistry					
Species	PM10, PMcoarse, PPM2.5, EC, OCprim , SOA, SO4, NO3, NH4, Na+, Cl-	PPM2.5, PPMcoarse, EC, OCprim, SO4, NO3, NH4	*SO_4, NO_3, NH_4, SOA from terpenes,* PM2.5, PMC, BC, sea salt	SO4, NO3, NH4, sea salt, PM2.5, PMcoarse, PPM2.5, PPMcoarse	Sulfate, Nitrate, Ammonium, SOA, PPM, water, wind blown dusts
Approach	Bulk approach		Bulk	Bulk approach	Sectional approach
Bin number		3 size bins for PPM	Fine and Coarse	Fine and Coarse	4 bins between 40 nm and 10 µm.
Equilibrium module	ISORROPIA	$NH_4NO_3 \leftrightarrow NH_3 + HNO_3$ RH & T dependent equilibrium constant (Mozurkewich, 1993)	ISORROPIA	EQSAM (Metzger et al., 2002) Or alternatively RH & T dependent equilibrium constant by Mozurkewich, (1993)	ISORROPIA
SOA	SORGAM module + terpenes, pinene, limonene.	Not included	Not used in this study	Not included in this study	Included for both anthropogenic and biogenic
Resuspension	- function of friction velocity and soil nature for mineral aerosol. - both direct and indirect entrainment of small particles - saltation is accounted	None	Not used in this study	Not included in this study	Telluric dusts from local erosion or from boundaries and resuspended particles are included.
Sea-salt	function of size and wind speed (Gong et al., 1997)	Not used in EuroDelta	Not used in this study	Implemented, but not used in Euro-Delta	not included

	RCG	MATCH	EUROS-LOTOS	EMEP	CHIMERE
Other		- Only few chemical reactions for ammonia-ammonium conversion - No aerosol dynamics included (except deposition and hygroscopic growth).		- No aerosol dynamics included, no chemical speciation of primary aerosol included in this study.	
Coarse SIA	No coarse SIA, all SIA components are assigned to PM2.5	All SIA components are assigned to PM2.5	All SIA components assigned to PM25	Coarse NO3 formation (on sea salt) included depending relative humidity	- Coarse nitrate not included - Part of nitrate, ammonium and sulphate in coarse mode. About 40 % of SIA is coarse.
Dry deposition	Resistance analogy	- resistance approach depending on land-use (four different land-use) - PPM: Zhang et al., 2001	Resistance approach dependent on land-use (9 land use classes)	Resistance approach depending on 16 landuse classes and varying by compound, - For ozone, stomatal flux calculations are included . - For ammonia and SO2, so-deposition processes are included according to Smith et al., 2003.	Resistance approach (Wesely, 1989)

	RCG	MATCH	EUROS-LOTOS	EMEP	CHIMERE
Wet Deposition	*Gases*: function of the species dependent Henry constant and precipitation rate. *Particles*: simple scavenging coefficient approach with identical coefficients for all particles.	Gases: proportional to precipitation and a species-specific scavenging coefficient	Below cloud scavenging is described using simple scavenging coefficients for gases (Schaap et al., 2004) and following Simpson et al. (2003) for particles. In-cloud scavenging is neglected.	*Gases*: proportional to precipitation and a species-specific scavenging coefficient, both in-cloud and sub-cloud *Particles*: Both in-cloud and sub-cloud scavenging coefficients.	*Gases*: function of the species dependent Henry constant and precipitation rate. *PM* In-cloud and sub-cloud scavenging are included

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Appendix B. EMISSIONS QA/QC

B.1 Introduction

The Eurodelta model intercomparison exercise aims at identifying differences in model responses to various emission-reduction scenarios. In order to ensure a meaningful comparison of model results, the same emission data and meteorological year have been imposed to all models as input conditions. In addition, prescribed sectoral- and country-dependent time and height profiles have been prescribed to all models. Since the application of prescribed emissions in a given model usually requires a series of operations, in particular an interpolation to the model grid, (each potentially leading to some divergence from the original data) it has been agreed in the frame of the exercise to perform a detailed check on the emission data that is effectively used within the different models. This section provides an overview of the comparison of the emissions used in each model with the prescribed input data for NH3, NOx, SOx, and PM2.5.

B.2 Methodology

The original emission data are for the year 2000 and given in the EMEP 50x50 polar stereographic projected grid for the following pollutants: NOx, SOx, NH3, PM2.5, PM10, CO and NMVOC. Emissions for each country are prescribed for each activity sector at SNAP level 1. For each of these activity sectors, emissions have been injected into the models at different heights to reflect the difference between ground level sources (such as road traffic) and emissions from large point sources that have tall stacks. To have as nearly similar a height distribution as possible across models the EMEP distribution was used throughout (B.5 Table 9). The release heights include an allowance for buoyant plume rise. Emissions also vary with time and monthly, daily and hourly factors have been provided as well in terms of sector (hourly) or in terms of sector and country (daily and monthly).

Because each model (with the exception of EMEP) must interpolate the EMEP projected emissions into its own grid and apportion it to the different countries within that grid there is scope for differences to be introduced into the emission distribution that are, to a large extent unavoidable. For example, some time shift could be introduced due to the different time zones assumed for the same cell in different models. To avoid interpolation to significantly perturb the comparison, emissions have not been checked on an hourly but on a monthly basis. It is then expected that these time differences resulting from interpolation are smoothed out and provide a meaningful comparison.

The following data have been provided by each modelling group for each grid cell in their own grid:

1. Monthly SOx emissions for January
2. Monthly NH3 emissions for April
3. Monthly NOx emissions for July
4. Monthly PM2.5 emissions for October

All data (excepted EMEP) have then been interpolated back to the EMEP grid to allow an easier comparison with the original input. As models do run on different grid configurations and domain extensions, the comparisons made hereafter are based on the area defined by the intersection of the 5 model domains (see figure below). Country totals refer therefore only to the part of the country included in this intersection. Note that near the boundaries, modelled emission data in original grids may sometimes fill partly the corresponding EMEP cell. Slight differences between the provided input data and modelled emissions are therefore to be expected at those locations.

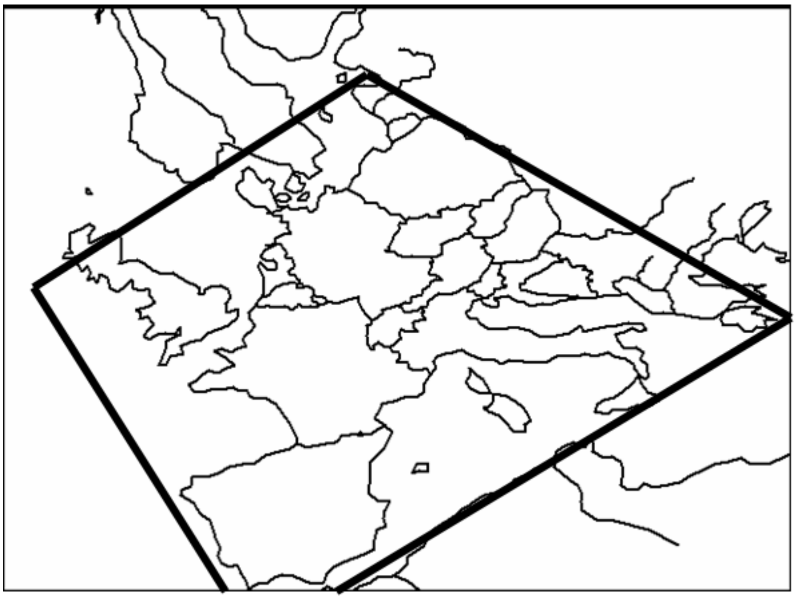

Figure 44. Domain over which the comparison between input and modelled emissions is performed. It is defined as the intersection of the 5 modelling areas.

B.3 Comparison of model monthly emissions with input data

a) SO2 emission check

A comparison of model SO2 emissions across countries is provided in Figure 45 below. With the exception of Italy (country code 15, see Annex 2) and the Mediterranean sea (33), all models produce values in close agreement with the input data. Due to interpolation from the original model grid to the EMEP projection, some volcanic emissions (e.g. Etna) fall into the Mediterranean whereas they are included originally in Italy. A shift of the emissions between these two countries/areas is then visible. This is the case especially for MATCH and to a lesser degree for REM and CHIMERE. Despite these shifted emissions these 3 models do keep total SO2 emissions close to the input data (within 3% accuracy). This is not the case, however, for EMEP which does overestimate the total SO2 emissions on the intersection domain by more than 20%. This results from a double counting of the volcanic emissions. In the case of LOTOS, volcanic emissions are assumed to be released above ~ 3.5 km height which is below the "top" of the atmospheric model and therefore do not appear in the inventory of modelled sources. Thus in this comparison the LOTOS total is deliberately smaller by approximately 20% and this is clearly seen if we zoom in to the volcanic area as shown in Table 8. This also shows that the EMEP model seems to have double counted volcanic emissions.

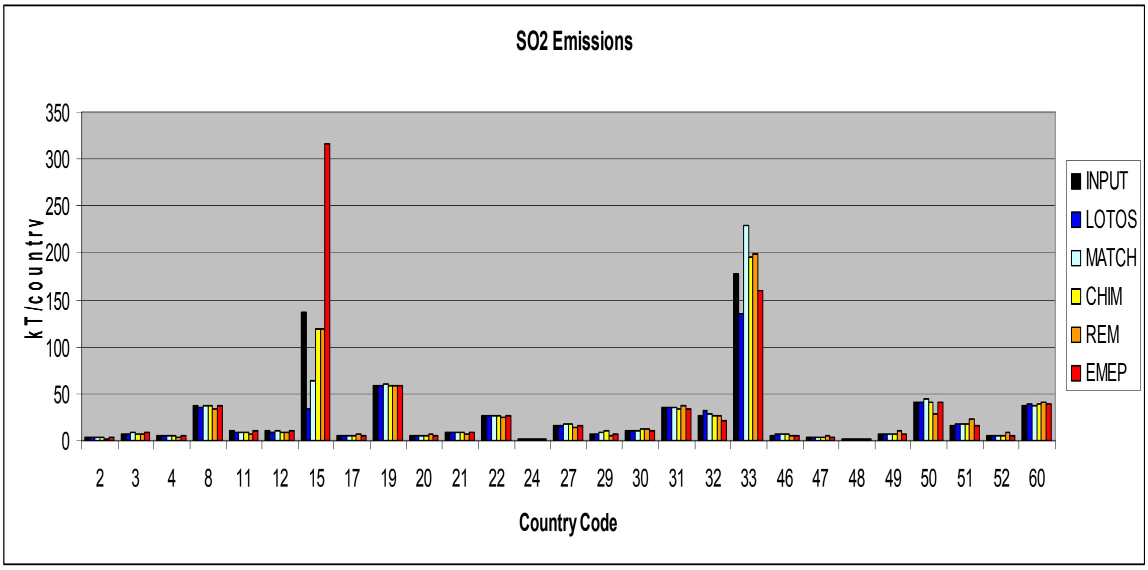

Figure 45: Country comparison of SO2 emissions among models

	Emissions (kt)	SO2 concentrations (ppb)
INPUT	175	
REM	172	3.23
CHIMERE	169	1.82
EMEP	337	1.20
LOTOS	33	1.53
MATCH	154	1.85

Table 8: Comparison of total emissions and average concentrations over the volcanic emissions area (area of 200x200 km2 around Etna volcano corresponding to EMEP cells [90:93, 28:33])

b) <u>NOx emission checks</u>

A comparison of model NOx emissions across countries is provided in the Figure 46 below. There is a close agreement between all models regarding total emissions with differences of the order of 1% for MATCH and CHIMERE, 5% for REM and 6% for EMEP. In the case of REM and EMEP, the overestimation reaches relatively large values in some countries as indicated in the table below:

	EMEP	REM
FRANCE	+11%	
GERMANY	+10%	+14%
NETHERLANDS		+21%
ITALY		+13%

The large REM overestimation over the Netherlands even peaks at 50% at some grid cells. Interpolation artefacts may be responsible for shifting emissions between the Netherlands and its neighbouring countries. It should be noted that models internally calculate a biogenic contribution of NO from soil to the specified anthropogenic distribution and this can increase the modelled total NOx emission compared to the input NOx distribution.

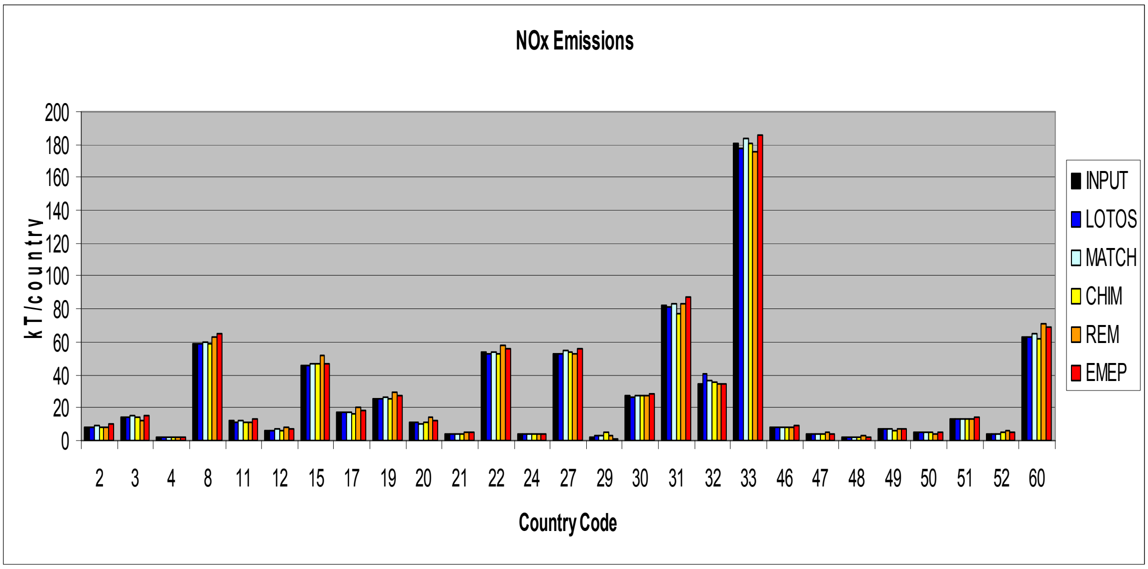

Figure 46. Country comparison of NOx emissions among models

A comparison of the total emissions over the Paris region (area of 250x250 km2 centred over Paris) with the average NOx concentrations as produced by the different models is given in the table below:

	Emissions (kTons)	Delta Emis	Mean NOx Concentration
INPUT	10232		
CHIMERE	9732	-5%	7.25
REM	10727	+5%	8.42
EMEP	11488	+12%	5.54
MATCH	10388	+2%	5.83
LOTOS	10150	-1%	5.82

As seen from the table, differences in concentrations are not related to differences in emissions. In fact, with the exception of REM, the highest emissions differences occur with the lowest concentration levels!

c) <u>NH3 emission checks</u>

A comparison of model NH3 emissions across countries is provided in Figure 47 below.

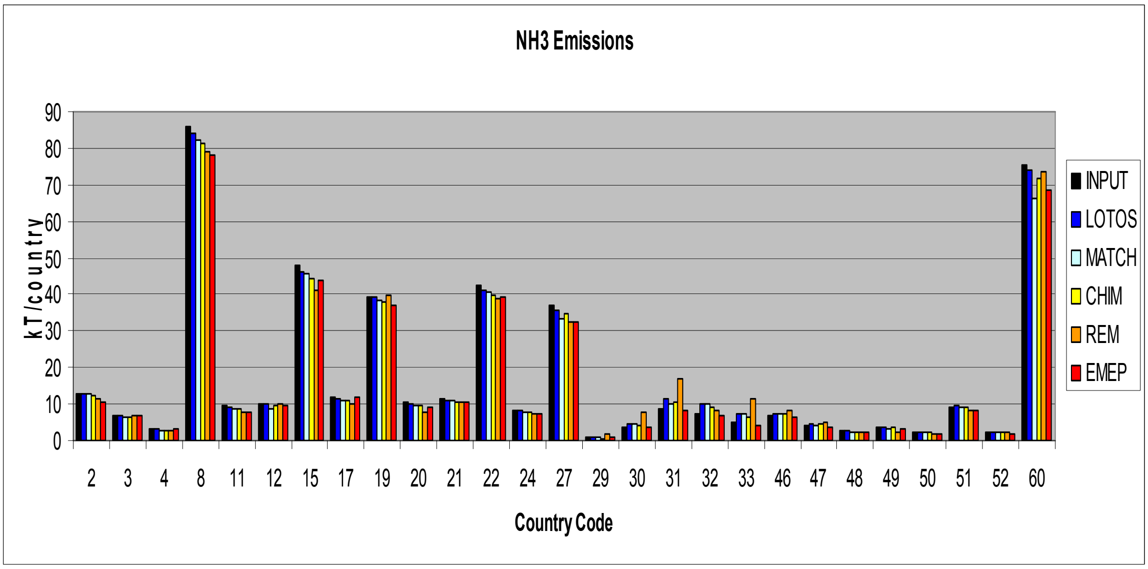

Figure 47 Country comparison of NH3 emissions among models

All models do underestimate the total input emissions although agreement is good. Differences are smaller than 5% with the exception of EMEP which underestimates the total emissions by about 9%. Details of NH3 emissions in three major emitting areas (Brittany (F), Po-Valley (I) and the Netherlands) is provided below. Similarly to NOx emissions, differences in emissions do not relate to differences in concentrations. This is particularly true for REM which produces the highest NH3 levels over Brittany and the Po-Valley making use of the lowest emissions. REM concentrations are in most cases twice as large as any other models.

	Region	Emissions (kTons)	Delta Emis (%)	NH3 Concentration (ppb)
INPUT	Brittany	25502		
EMEP		23241	-9	3.16
CHIMERE		24442	-4	3.35
REM		24063	-6	6.05
LOTOS		25261	-1	2.87
MATCH		25107	-1	2.47
INPUT	Po-Valley	27560		
EMEP		25082	-9	3.99
CHIMERE		26283	-5	6.68
REM		24705	-10	9.58
LOTOS		27265	-1	4.74
MATCH		26843	-3	4.12
INPUT	Netherlands	30735		
EMEP		29109	-5	4.55
CHIMERE		29444	-4	4.64
REM		29001	-6	8.73
LOTOS		30548	-11	3.92
MATCH		29124	-5	4.23

d) PM2.5 emission checks

A comparison of model PM2.5 emissions across countries is provided in Figure 48 below. All models do closely agree with the total input emissions (within a range of 3%)

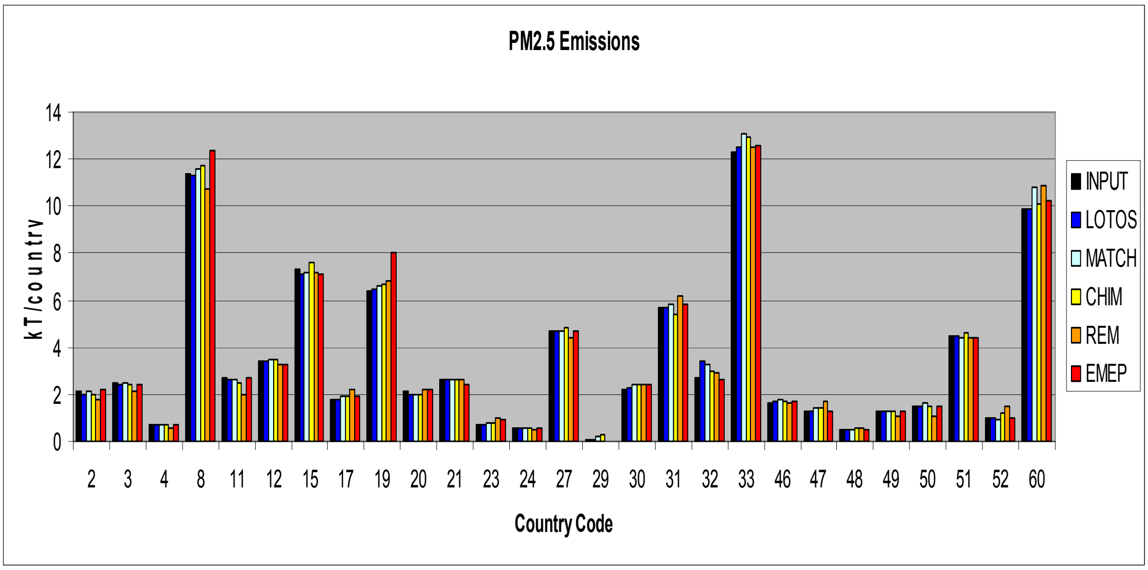

Figure 48. Country comparison of $PM_{2.5}$ emissions among models

B.4 Conclusions

Although most of the input data, and especially emissions, have been imposed to all models, the models may internally calculate further emissions, for example from biogenic sources depending on the internal land use assumptions etc. Thus a check on the real emissions (as used within the calculations) has been made to ensure that all models run with similar emission data.

Because the original emissions were provided in the EMEP projected grid, all models (except EMEP) had to interpolate the data to their own grid. To enable the comparison of total emissions on the common (EMEP) grid this procedure was then reversed. This double interpolation procedure may contribute to some of the differences (output vs input) observed when comparing, for example, country total emissions.

The comparison of PM2.5 emissions illustrated a very close agreement between all models with the imposed input data. In the case of SO2, the EMEP and LOTOS data show a significant difference in terms of total emissions over the complete domain (defined as the intersection of the 5 model areas). These differences are localized around the volcanic emissions which LOTOS omits because the release height of 3.5 km is above the “top” of its model domain. EMEP appears to double-count the volcanic emissions. There seems to be little impact on SO_2 concentrations at ground level.

All models do underestimate the NH3 emissions evenly across countries. In the case of EMEP, this underestimation is more significant probably due to the time profiles used which are different from those prescribed to the exercise participants.

In the case of NOx emissions, EMEP and REM do overestimate the emissions with maximum percentage of about 10% in Germany and France. This could be related to the inclusion biogenic emissions of NO from soils in those models.

As a general conclusion the differences in emissions do not directly relate to the differences in concentrations as demonstrated for NOx and NH3.

B.5 Emission Height distribution table

Snap sector		Vertical layer mean height (m)					
		0-90m	90-170m	170-310m	310-470m	470-710m	710-990m
1	Public Power stations	-	-	8%	46%	29%	17%
2	Comm./inst. combustion	50%	50%	-	-	-	-
3	Industrial combustion	-	4%	19%	41%	30%	6%
4	Production processes	90%	10%	-	-	-	-
5	Extraction fossil fuel	90%	10%	-	-	-	-
6	Solvents	lowest layer	-	-	-	-	-
7	Road traffic	lowest layer	-	-	-	-	-
8	Other mobile (trains, plains etc.)	lowest layer	-	-	-	-	-
9	Waste	10%	15%	40%	35%	-	-
10	Agriculture	lowest layer	-	-	-	-	-
11	Nature	lowest layer	-	-	-	-	-

Table 9. Percentage allocation of emissions at different height levels according to emission sector. The same height distribution is to be used for all pollutants.

The proposed height distribution is the one used by the Unified EMEP model since September 2002. It is based on data provided by Sonja Vidiç (personal communication, September 2002) from a study of the effective height of emissions from 7 power plants and 1 industrial plant in Zagreb (Croatia). The study was carried out using three different physical heights of plants: 60m, 150m, 200m and using actual meteorological conditions from 1997-2001. The plant emission dispersion was modelled following Brigg's formula and results were presented in a monthly basis. In EMEP, the results have been parameterised as indicated in Table 1, considering a typical averaged height of 150m for point sources over Europe and using the same annual variation for all countries.

B.6 Country number list

EMEP Nb	CountryAcronym	Country Name
1	AL	Albania
2	AT	Austria
3	BE	Belgium
4	BG	Bulgaria
6	DK	Denmark
7	FI	Finland
8	FR	France
11	GR	Greece
12	HU	Hungary
13	IS	Iceland
14	IE	Ireland
15	IT	Italy
16	LU	Luxembourg
17	NL	Netherlands
18	NO	Norway
19	PL	Poland
20	PT	Portugal
21	RO	Romania
22	ES	Spain
23	SE	Sweden
24	CH	Switzerland
25	TR	Turkey
27	GB	United Kingdom
28	VOL	Volcanic_emissions
30	BAS	Baltic Sea
31	NOS	North Sea
33	MED	Mediterranean Sea
34	BLS	Black Sea
43	EE	Estonia
44	LV	Latvia
45	LT	Lithuania
46	CZ	Czech Republic
47	SK	Slovakia
48	SI	Slovenia
49	HR	Croatia
50	BA	Bosnia and Herzegovina
51	CS	Serbia and Montenegro
52	MK	The former Yugoslav Republic of Macedonia
55	CY	Cyprus
56	AM	Armenia
57	MT	Malta
59	LI	Liechtenstein
60	DE	Germany

Appendix C. GRAPHICAL VISUALIZATION TOOL

C.1 Introduction

Results from 6 models covering about 60 different emission-reduction scenarios have been delivered in the course of the Eurodelta exercise. In order to facilitate comparison of the results, an IDL-based visualization tool has been developed which allows working interactively and off-line on the results. After pre-processing, a subset of the originally received data is made available through internet and installed on each individual participant PC. This section describes the model results pre-processing (section 2) and provides an overview of the main graphical features (sections 3 to 5). Some details about the quality control of the model results are given in Section 6 and some concluding remarks given in Section 7.

C.2 Data pre-processing

Each modeling groups delivered 60 years of hourly surface data, summing up to a total amount of 360 Gb. This amount of data has prevented a direct use of the data and implied some pre-processing stage. Two distinct groups of data have been generated from these original data through pre-processing for each delivered species: the first includes hourly data at locations corresponding to the EMEP monitoring stations (see Section 3) whereas the second includes monthly averaged surface data (see Section 4). The total processed data amounted then to about 10 Gb. All processed data were then made available through the Eurodelta Web page to all participants.

C.3 Temporal point to point model comparisons

The analysis of hourly data at given locations is performed with the ‘Delta” option within the visualization tool. Although no validation with measurements is made in this phase of the Eurodelta project, locations at which hourly data are analysed correspond to the EMEP monitoring stations. Due to the large number of EMEP monitoring locations which amounts to 150, processed data have been distributed into 9 different regions. Among the stations belonging to a given region, 9 may be visualized contemporaneously.

The visualization tool is built in a flexible way to facilitate interactivity. After an initial choice of the region and stations of interest, the user may select the species, indicator and emission scenario (or emission difference) to analyse. According to the indicator choice, some tuning parameters (threshold value, time average,…) become active and may be set to given values. A list of the possible species and indicators is given here below:

Species	_Gas-phase_: O3, NO, NO2, NOx, Ox, HNO3, H2O2, HCHO, SO2, NH3 _Aerosol-phase_: Primary PM25, Primary PM10, PM25, PM10, Sulfate, Nitrate, Ammonium, Secondary Inorganics, Black Carbon, Organics _Other_: SO2/NOx/NHx wet deposition, SO2/NOx/NHx dry deposition, SO2/NOx/NHx total deposition
Indicator	_Time series_: Hourly values for O3, NO2 and Ox and daily averaged values for aerosols are shown for the selected models.

	Mean-ddn: Time series of mean value. ddn indicates the choice: daily, day, night *Max/Min/Mean/Stddev-T*: Maximum/Minimum/Mean/Standard deviation value over the selected time period of time. *Mean/Stddev-S*: Mean/standard deviation value over the 9 selected locations. *Mean/Stddev-M*: Maximum, standard deviation value over the selected models. *Freq_A*: Frequency analysis showing the distribution in percentages of model results over size bins of given width. *AOTx: AOT* (sum of the hourly values by which the species exceeds the threshold x over the selected period of time. For aerosols the daily exceedance is multiplied by 24. *SOMOx*: Sum of the maxima of the daily 8-hr running average concentration in excess to the threshold x *Exc days*: Number of days within the selected period of time during which the species exceeds the threshold value. Example: Ozone 8hr running mean value with threshold 60 ppb may not exceed 25 days per year.

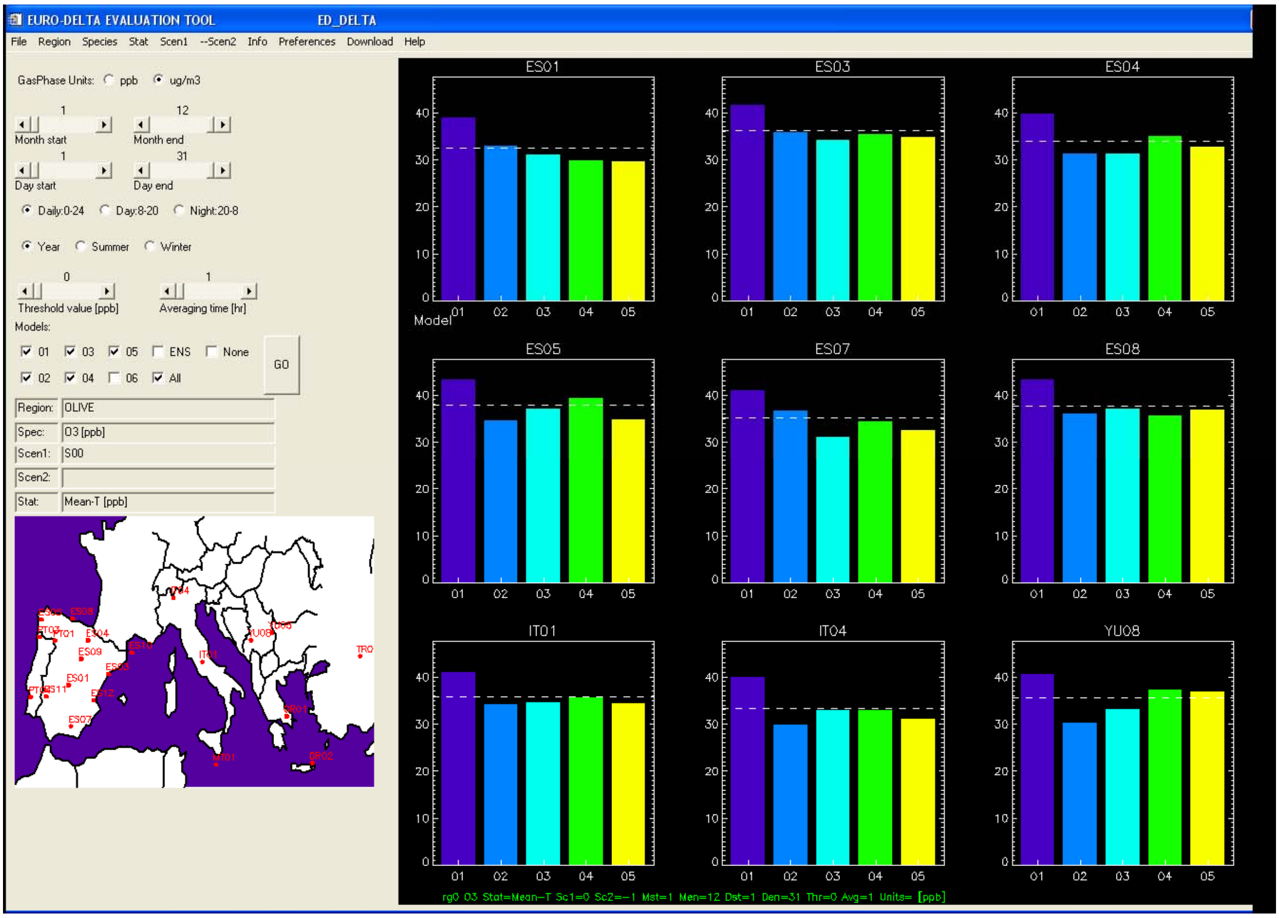

Figure 49: Illustration of the "Delta function" of the visualisation tool showing a Comparison of O3 mean values at 9 stations within the Mediterranean region

C.4 Surface time-averaged model comparisons

The analysis of surface monthly averaged data is performed with the ‘Plane” option within the visualization tool. Model results in their original projection are interpolated on two different grid configurations: latitude-longitude or EMEP. Similarly to the “Delta” option described above, the user may select the species, indicator and emission scenario (or emission difference) to visualize. To compare the modelled impact of emission reductions from different scenarios among themselves, a possibility has been built in which allows to scale the modelled concentration delta by the amount of reduced emissions. Population weighting of the results is also available. A list of the possible species and indicators is given here below:

Species / Indicators	*Gas-phase*: O3, AOT-40, SOMO-0, SOMO-35, Exc60, MOLL, YOLL, NO, NO2, NOx, Ox, HNO3, H2O2, HCHO, SO2, NH3 *Aerosol-phase*: Primary PM25, Primary PM10, PM25, PM10, sulfate, nitrate, ammonium, Secondary Inorganics, Schaap, Black Carbon, Organics *Other*: SO2/NOx/NHx wet deposition, SO2/NOx/NHx dry deposition, SO2/NOx/NHx total deposition

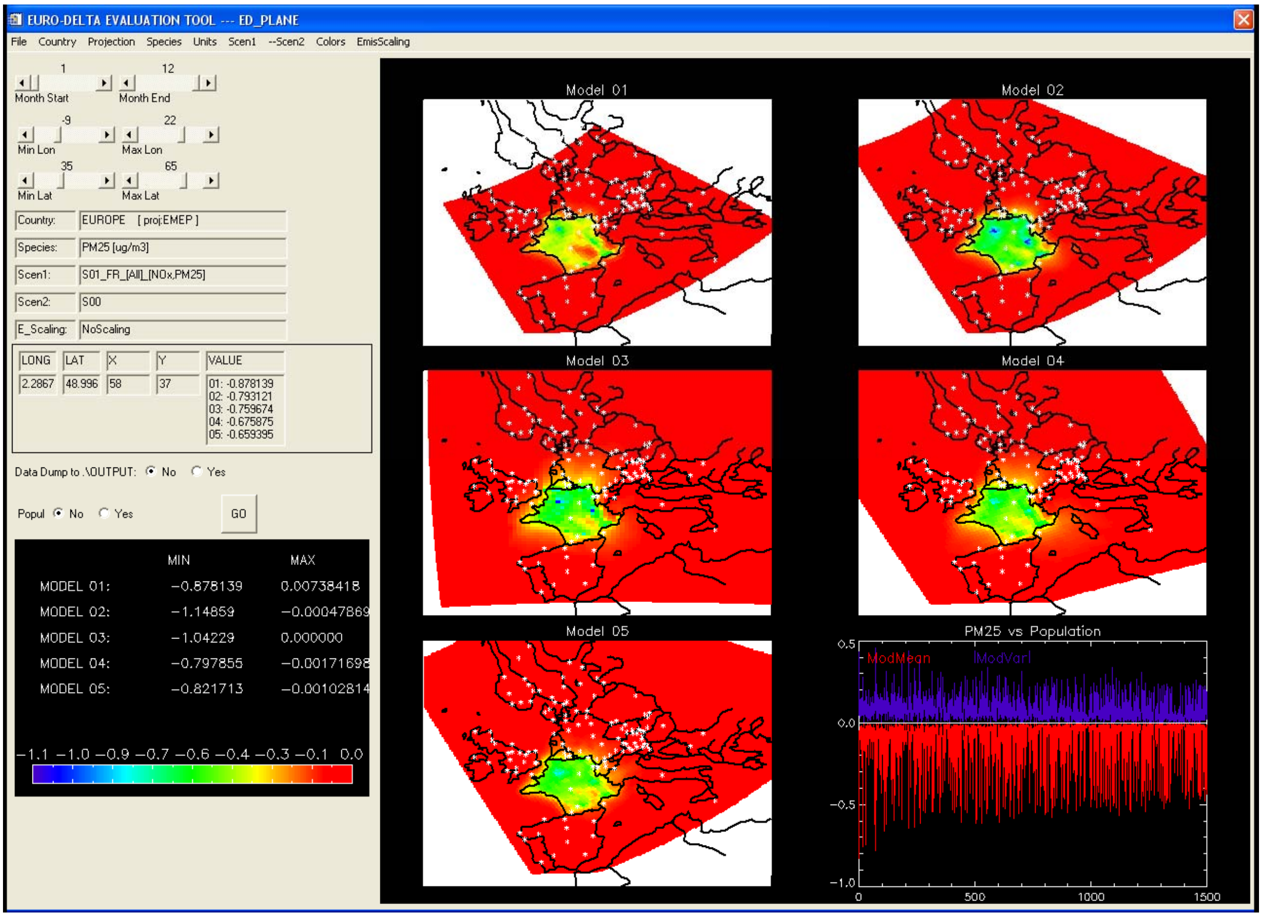

Figure 50: Illustration of the "Plane" option capabilities. Comparison of modelled surface PM2.5 fields. The right lower panels provides the model variability (Max-min) in blue as well as the model mean in red in terms of population density (highest density on left of axis)

C.5 Transects and country averages

For terrestrial scenarios, a series of emission reductions has been defined for each country (France, UK, Germany and Spain) in order to compare the impact of emission reductions imposed on different activity sectors. A specific option has been built in the visualization tool to facilitate this comparison. For any given location, the graphical tool allows comparing the different model responses along a North-South and East-West transects. In addition, responses corresponding to different sectoral reductions can be compared along these transects. Model results can be scaled with respect to emission reduced amounts or weighted with population (see Figure 51).
Results can also be aggregated in terms of countries (Figure 52)

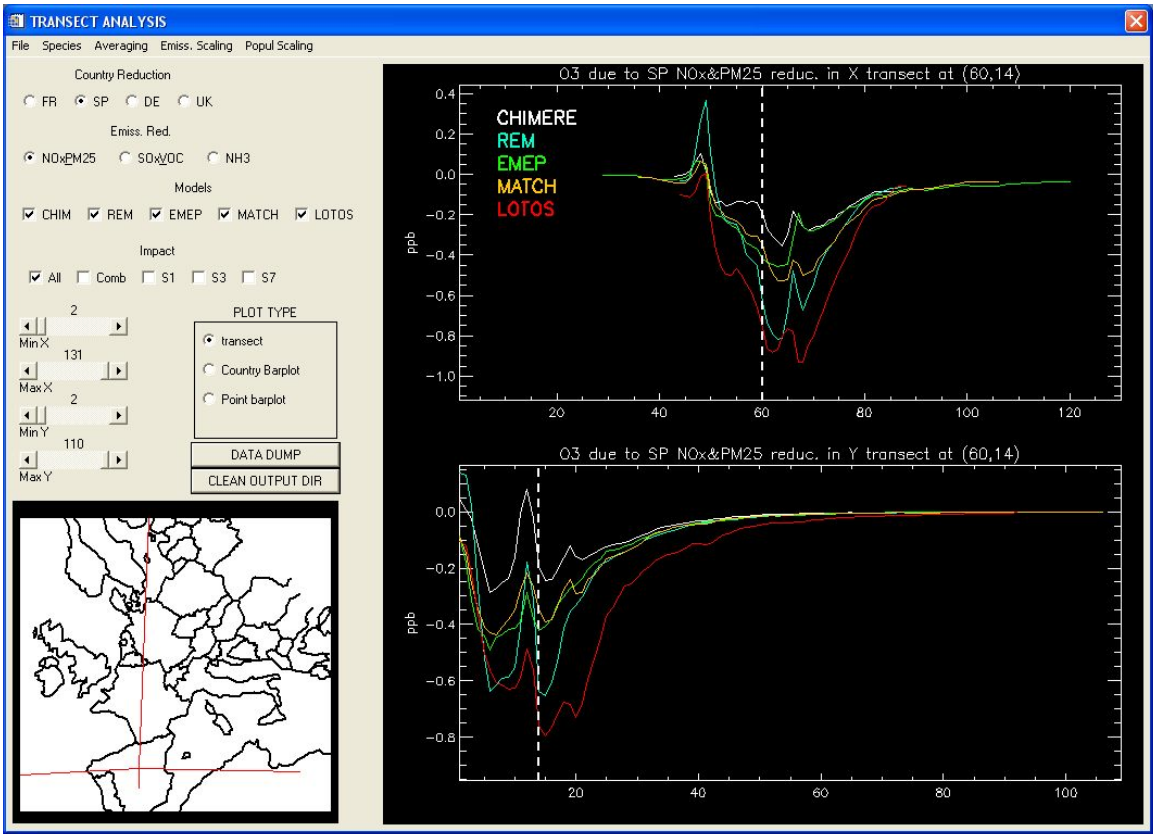

Figure 51: Transect tool: comparison of modelled responses to NOx and PM2.5 emission reduction in SPAIN along a N-S and E-W transects crossing EMEP location (60,14) indicated on the lower left map.

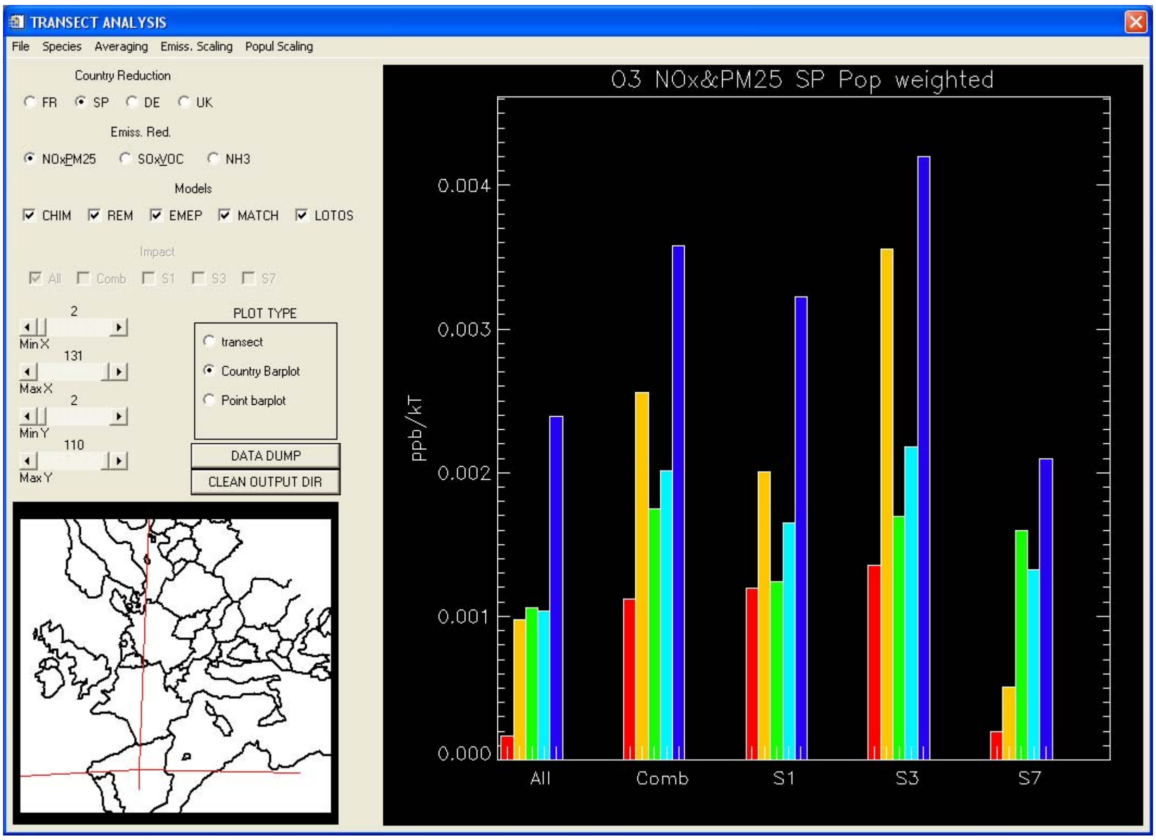

Figure 52: Transect tool: similar to Figure 51 but modelled responses are aggregated by country.

C.6 Model results QA/QC

Although no formal procedure to guarantee the quality of the results has been followed, a series of controls have been made. This starts with the pre-processing stage where all modelled field maximum and minimum values are tested. Missing variables and/or formatting mistakes are identified at this stage. In addition to this preliminary test, the main quality control consists in comparing model results among each other. Identification of outliers very often resulted in problems to be resolved.

C.7 DVD

A DVD set containing the results of the Eurodelta II project is available on application to: C. Cuvelier, European Commission, DG Joint Research Centre, Institute for Environment and Sustainability, Ispra (Va), Italy.

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Abstract

The EURODELTA II (ED II) project is the second phase of the EuroDelta co-operation project. The EuroDelta co-operation is intended to support the design of air pollution control strategies in Europe, both under the European Commission and under the Convention on Long-range Transboundary Air Pollution.

The EuroDelta approach is to investigate the robustness of source-receptor relationships used in Integrated Assessment (IA) modelling by introducing an ensemble of models. The project is based on a collaboration between the European Commission Joint Research Centre (JRC) at Ispra (Italy) , five air quality modelling teams at Ineris (France), the Free University of Berlin (Germany), Met.no (Norway), TNO (Netherlands) and SMHI (Sweden) and the Oil Companies' European Organization for Environment, Health and Safety (CONCAWE).

While the first phase of EuroDelta, ED I, examined the feasibility of using model ensembles to evaluate the robustness of source-receptor calculations in predicting recent (2000) and future (2020) air quality in Europe, the second phase ED II investigates the consequences of introducing sectoral approaches in integrated assessment modelling.

A total of 60 different emission scenario calculations were evaluated to determine how the different models represent the impacts on a European scale of applying emission reductions to individual emission sectors. Emission reductions from power combustion, industry, residential and traffic sources were investigated independently and additional efforts were also addressed to investigate the effect of shipping emission control in the Mediterranean Sea.

The main conclusion is that the impact of emission reductions in individual sectors is more appropriately described with the help of sectorally disaggregated source- receptor calculations. The recommendation is to incorporate sectoral weights to integrated assessment modelling in order to better support future revisions of European air pollution control policies

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